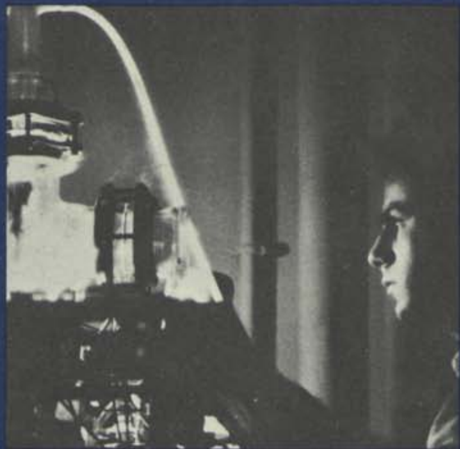
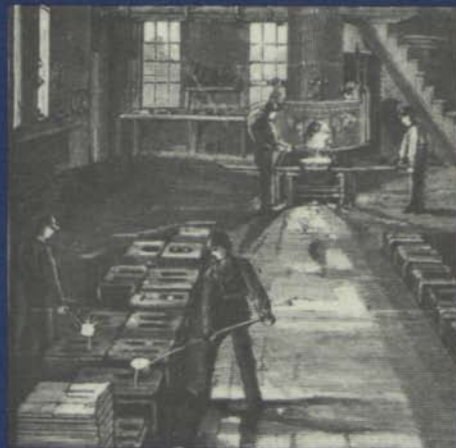
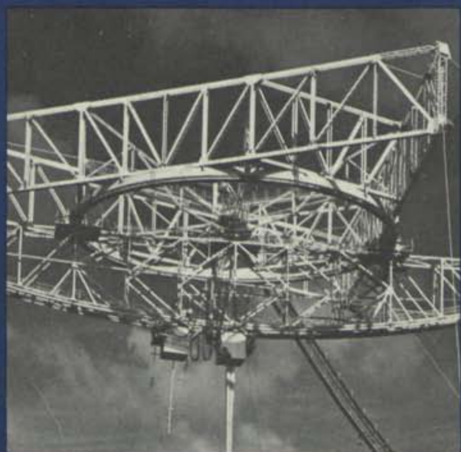
ENGINEERING

CORNELL QUARTERLY



VOLUME 1

SUMMER 1966

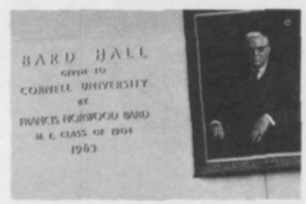
ENGINEERING
NEW
MATERIALS

IN THIS ISSUE

Progress in materials science during the last thirty years has accelerated man's exploration in space, development of supersonic aircraft, use of nuclear reactors, and fabrication of products only dreamed of previously. Walter S. Owen, Director of Cornell's Materials Science and Engineering Department, surveys this progress and discusses Cornell's role in solving new materials science problems.

Beginning as an observation of metallurgical phenomena in the mechanics laboratory, materials science has broadened and deepened to become the study of the atomic and molecular structure of materials and of their relationship to materials properties. Malcolm S. Burton, Professor of Materials Science and Engineering, discusses this development and its importance to industrial progress.

A tour of the facilities of the Department of Materials Science and Engineering.



Part of America's search for knowledge of Space is conducted in an isolated "sinkhole" region of Puerto Rico. There, at the Arecibo Ionospheric Observatory, a 1000-foot radar-radio telescope is operated by Cornell engineers. Research at the Observatory daily extends man's knowledge of space and at the same time reveals some of its mysteries. Some of this new knowledge and the puzzles it presents are discussed in ENGINEERING's section on the Observatory and the man behind its design and development, Dr. Wiliam E. Gordon.

This month's Register pays tribute to three recently named Emeritus Professors in the College of Engineering: Professors Paul P. Bijlaard, Clyde W. Mason, and True McLean.

ENGINEERING: Cornell Quarterly, Summer, 1966, Vol. 1, No. 2. Published four times a year in April, July, October, and January, by the College of Engineering, Cornell University, Carpenter Hall, Campus Road, Ithaca, New York 14850. Second class postage paid at Ithaca, New York. Subscription rate: $2.50 per year.

Opposite: The surface of a high density sample of magnesia. Photo by Dr. P. Morgan, research associate in Materials Science and Engineering: enlargement approximately 23,000 x.

MATERIALS SCIENCE
An Engineering-Science Interface

By Walter S. Owen

Man's progress has been determined to a great degree by his capacity to develop and produce useful materials. We reflect progress in materials by dividing our history into the Stone Age, Bronze Age, Iron Age, and the Age of Steel, and for our recent quarter-century, into the Atomic Age and the Space Age. While the pattern associating the age with a single material has been broken, the great achievements of the postwar years have come through the development of a very large number of radically new materials. In fact, progress in both atomic energy and space has been —and still is—related to our abilities to meet exacting and specific materials requirements.

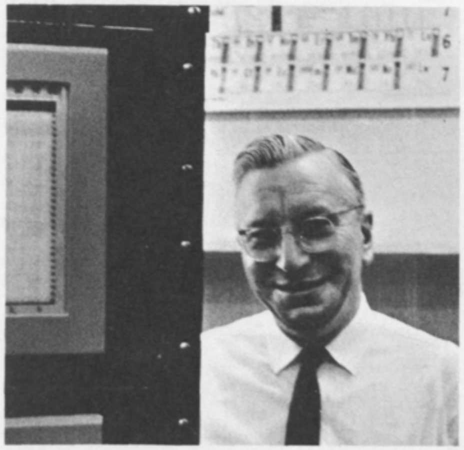
There are several ways in which a step forward can be made. As in the case of the gas turbine, the engineering concept may precede man's ability to make the hardware. For years the gas turbine remained an interesting but purely academic exercise on a drawing board. It was only through the concerted effort of a large number of materials scientists and a substantial expenditure of money that alloys were developed with the necessary creep-resistance at elevated temperatures for the manufacture of turbine blades.

A second way of "stepping forward" comes when improvement of the properties of existing materials stimulates the rapid development of either completely new or much improved designs. Think of the striking difference between the wooden-shafted golf clubs of fifty years ago and the modern steel clubs—or better still, the performance improvement in the art of pole vaulting! The introduction of fiberglas poles has led to record-breaking on a scale unprecedented in other athletic activities.

PUTTING ENGINEERING AND SCIENCE IN PHASE

The development of the art and science of engineering materials has not always paralleled the development of the chemistry and physics of materials, although the basic and the applied sciences have interacted in varying degrees. Steel, for example, had been known for thousands of years before the invention of the Bessemer and open-hearth processes made it possible to produce the material in the quantities required by modern engineering. Scientific knowledge and engineering application merge more closely today. During the last three decades our progress in producing materials exceeds that of the preceding three thousand years.

The development of the technology of aluminum alloys made modern aviation possible, and the successful outcome of an enormous program of research and development on titanium and its alloys will make the supersonic jet transport a reality. To bring the atomic nuclear reactor to its present sophisticated stage of development has required the perfection of a wide variety of different materials, ranging from alloys and compounds of uranium through the alloys of metals of Groups 5A and 6A (in the Periodic Chart of the Atoms) to unusual stainless steels and much improved low-alloy steels. A few years ago, more than one-third of the scientific manpower employed by agencies concerned with atomic power were devoting their efforts to the development of new materials.



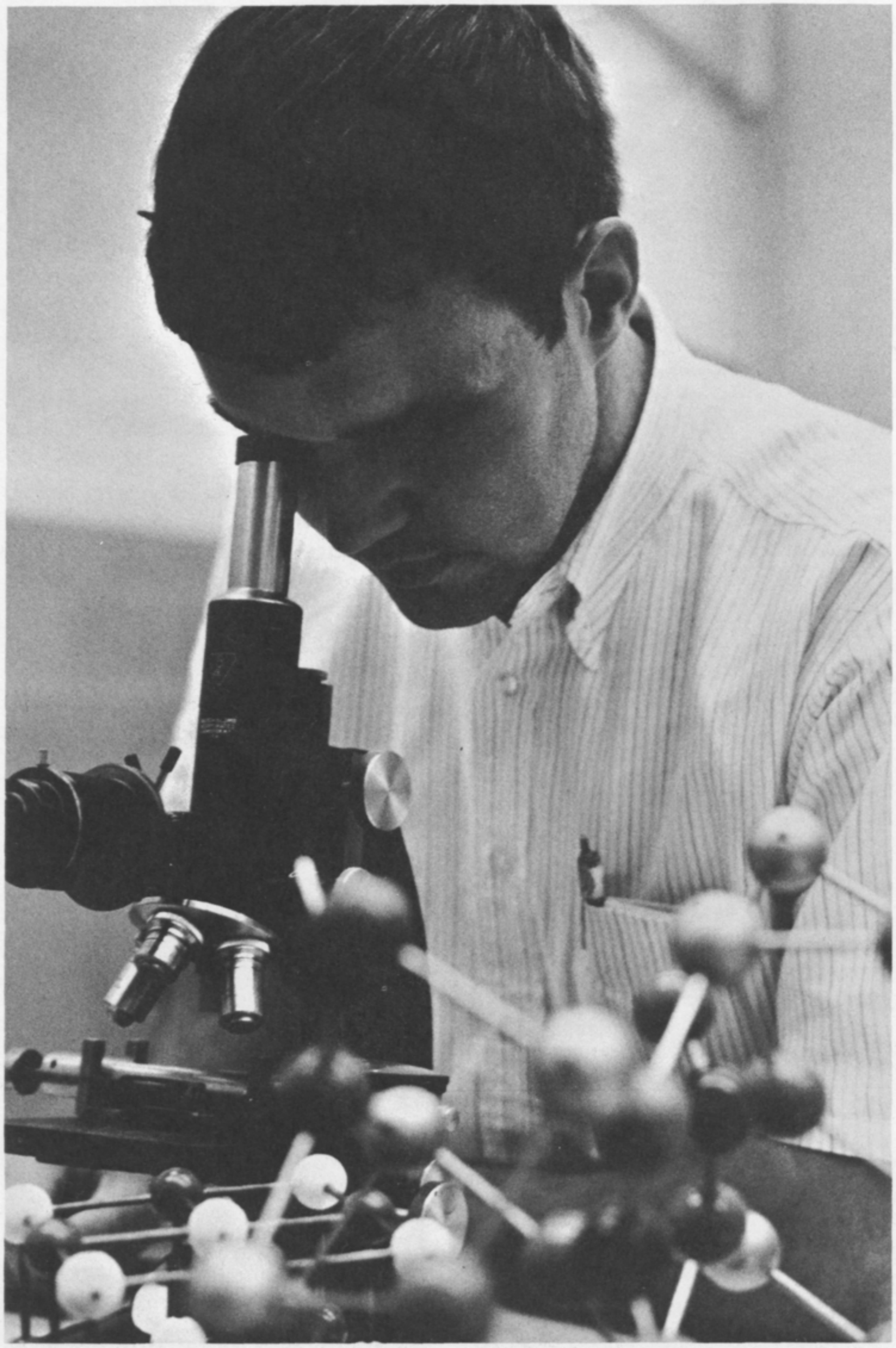
THE EMERGENCE OF THE MATERIALS SCIENTIST

By far the greatest challenge to the skill and ingenuity of the materials scientist has come from the space programs. Metallic materials occupy a central place in this program and much exciting work has been done on highly alloyed steels fabricated by unique thermal-mechanical treatments which have enhanced the strength properties to levels previously thought unattainable. In addition, one of the striking changes in emphasis which has occurred in recent years is the importance which now is attached to the work in areas such as glasses, ceramics, inorganic compounds, and plastics. All these materials play some essential role in the space program.

Paralleling these developments are the staggering advances made in electronic and magnetic engineering, paced largely by the development of new materials. The outstanding example is that of the development of the semiconductor. Recently the low temperature magnetic properties of certain metals and alloys have been exploited in a most profitable way and there is no doubt that we can expect rapid developments in this area in the near future.

All of these modern achievements in materials have come about through the emergence of a large, coherent, and systematized science of materials and a parallel development of materials engineering applications. It is difficult if not impossible to separate materials science from materials engineering. For example, some modern materials depend for their unique properties on the dispersion of small particles of the second phase in the parent matrix. The size, shape, and dispersion of the second phase is often determined by the thermal and mechanical treatments which the material receives during its manufacture and fabrication. While the materials scientist may decide on the optimum form of the dispersion, the materials engineer needs to find out how to produce and control this dispersion consistently in a commercial process.

Materials sciences have been practiced in a specialized form for many years. Probably the largest number of materials scientists have been concerned with metals. Physical metallurgy has certainly been one of the parents of modern materials science. The science and technology of ceramics, glass, polymers, and aggregates or composites of these, with or without metals, have been studied to different extents for the last fifty years. It is only within the last decade, however, that a unified science of materials has emerged. The key to materials science is structure: the electronic structure, the crystal structure, the nature and arrangement of defect in crystals, the way in which crystals are



fitted together in solids, and the morphologies which result.

The first studies of crystalline structure were carried out by the examination of the external form of some single crystals. A visit to the mineralogy section of any well-established natural history museum should serve to illustrate the fascination that the study had for scientists in the first half of the last century. Many of our present ideas about the symmetry of crystals and our systematic classification of crystal types stems directly from this earlier work, although it has long been recognized that the external shape adopted by a crystal reveals only a limited aspect of the internal crystalline arrangement of its atoms. Very few solids exist naturally as single crystals; most manufactured solids consist of many crystals fitted together to fill space. The boundaries between crystals in a polycrystalline mass affect the properties of the solid, and, because of this, the study of boundaries has become a major science.

OPTICAL EXAMINATION OF MATERIALS

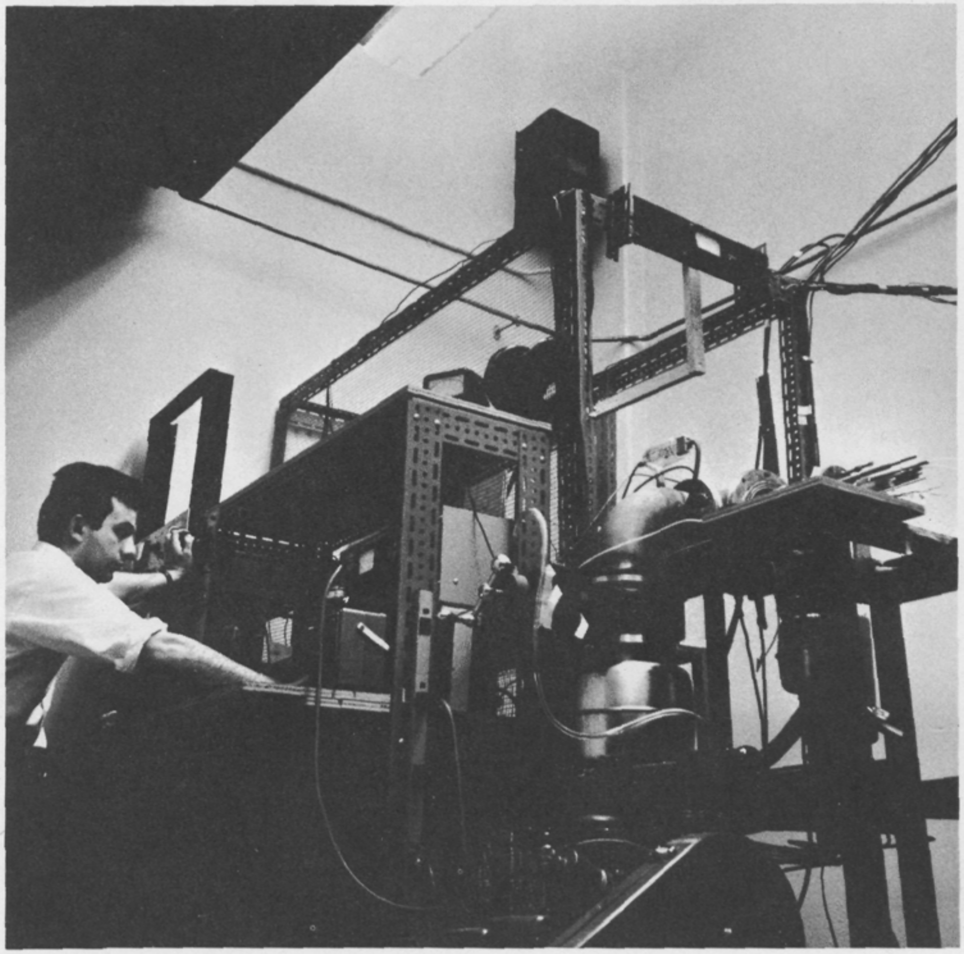
Attempts were made in the early years of the Victorian era to study the internal structure of polycrystalline aggregates, as well as single crystals, by optical microscopy but the techniques were limited to those materials which could be cut into sufficiently thin slices so that light could be transmitted through them. This technique is still widely used today for the study of many non-metallic materials.

The first successful optical examination of opaque materials, particularly metals and alloys, was carried out by Sorby just about a century ago. As a

1. Structural defects, a major area of research interest, are being examined in thin metallic foils in this apparatus.

2. Preparing the furnace of a hot compression molding press for the fabrication of ceramics.

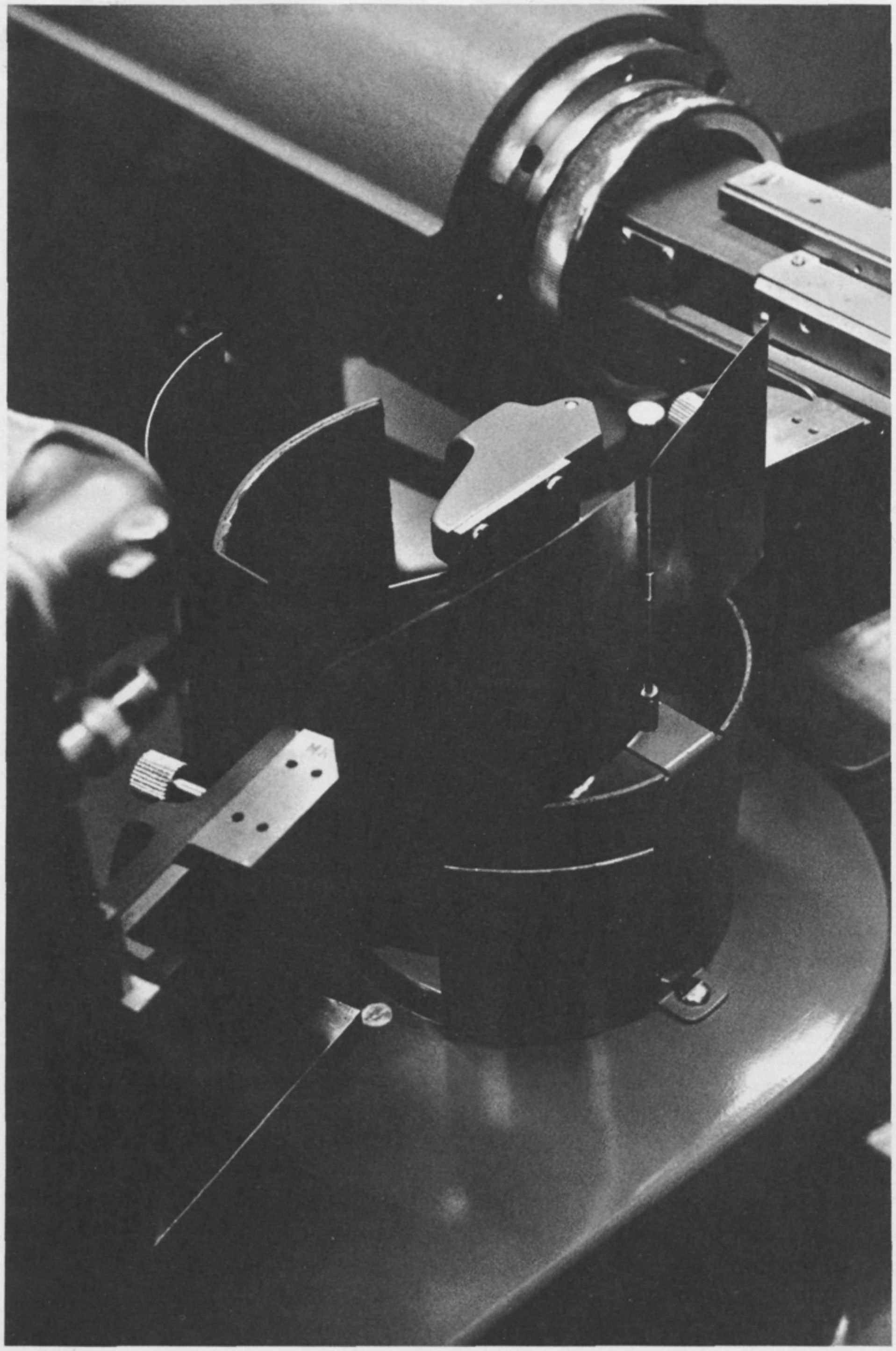
3. One of several laboratories in Bard Hall equipped for the preparation of crystals for experiment.



1

2

3



A close-up of a multiple-reflection x-ray diffractometer. Professor U. Bonse and Dr. M. Hart collaborated on the development of the theory and design of equipment which made it possible to perform x-ray interferometry for the first time. Precise measurement of the refractive index of x-rays, the thickness of small objects, and of extremely small lattice distortions, are among some of the possible applications of the Bonse-Hart equipment. Additional investigations involve the development of a multiple-reflection x-ray diffractometer for high resolution small angle scattering and x-ray spectroscopy.

steelmaster in Sheffield, England, he was a wealthy amateur scientist who was interested in mineralogy. It was natural that he should attempt to modify optical microscopy techniques to study steels. Through his successful experimentation he made a considerable contribution to metallography, still one of our major techniques for materials study in the laboratory.

Cornell has two modern metallographic laboratories for specimen preparation, including immersed-spark cutting and electrolytic polishing. Microscopes have also improved beyond recognition in the last hundred years. Today considerable use is made of dark field illumination, polarized light, and optical interferometry.

EMERGENCE OF X-RAY DIFFRACTION

From the time it was realized that the beautiful shapes which are adopted naturally by some crystals must reflect in some way the internal arrangement of the atoms, ways of investigating this crystalline arrangement have been sought. The answer was found when it was realized that crystals can act as diffraction gratings for x-rays. The numerous techniques of x-ray diffraction developed rapidly from this discovery. Much of the activity in the study of the structure of solids between the two World Wars was devoted to the applications of x-ray diffraction. Through progress in x-ray analysis many of the elemental metals were found to have relatively simple structures, although some rather complex arrangements of atoms occur in certain alloy systems. However, the crystal structure of many other important materials, such as silicates and polymers, are still the subject of intensive work. It will probably be some time before all the details of the structure of all the materials that we use or may use are properly and completely understood.

More recently, x-ray diffraction techniques have been extended to the study of crystalline defects. In this area they have produced some interesting results which supplement the more extensive information that can be obtained by electron microscopy. The x-ray diffraction facilities at Cornell, coordinated through the Materials Science Center, are supervised by Professor B. W. Batterman, who is doing some fascinating work on the details of the changes in structure which occur in certain superconducting compounds as the temperature is lowered below 20° absolute.

Many important properties of solids are affected to a pronounced degree by the size, distribution, and type of crystals which are mixed together in a polycrystalline aggregate on a scale which can be examined by optical microscopy; but it is equally clear that the structure on a finer scale than can be observed in this way is also very important. This was strikingly demonstrated not long after the First World War when techniques were devised for growing single crystals of some materials normally occurring only in the polycrystalline form in a number of laboratories in the United States, Britain, and Germany. These crystals were found to be much weaker than had been expected and certainly weaker than could be explained on any assumption that plastic deformation occurred as a result of a sheet of atoms sliding over the adjacent sheet like a deck of cards. From these

"It is only within the last decade... that a unified science of materials has emerged."

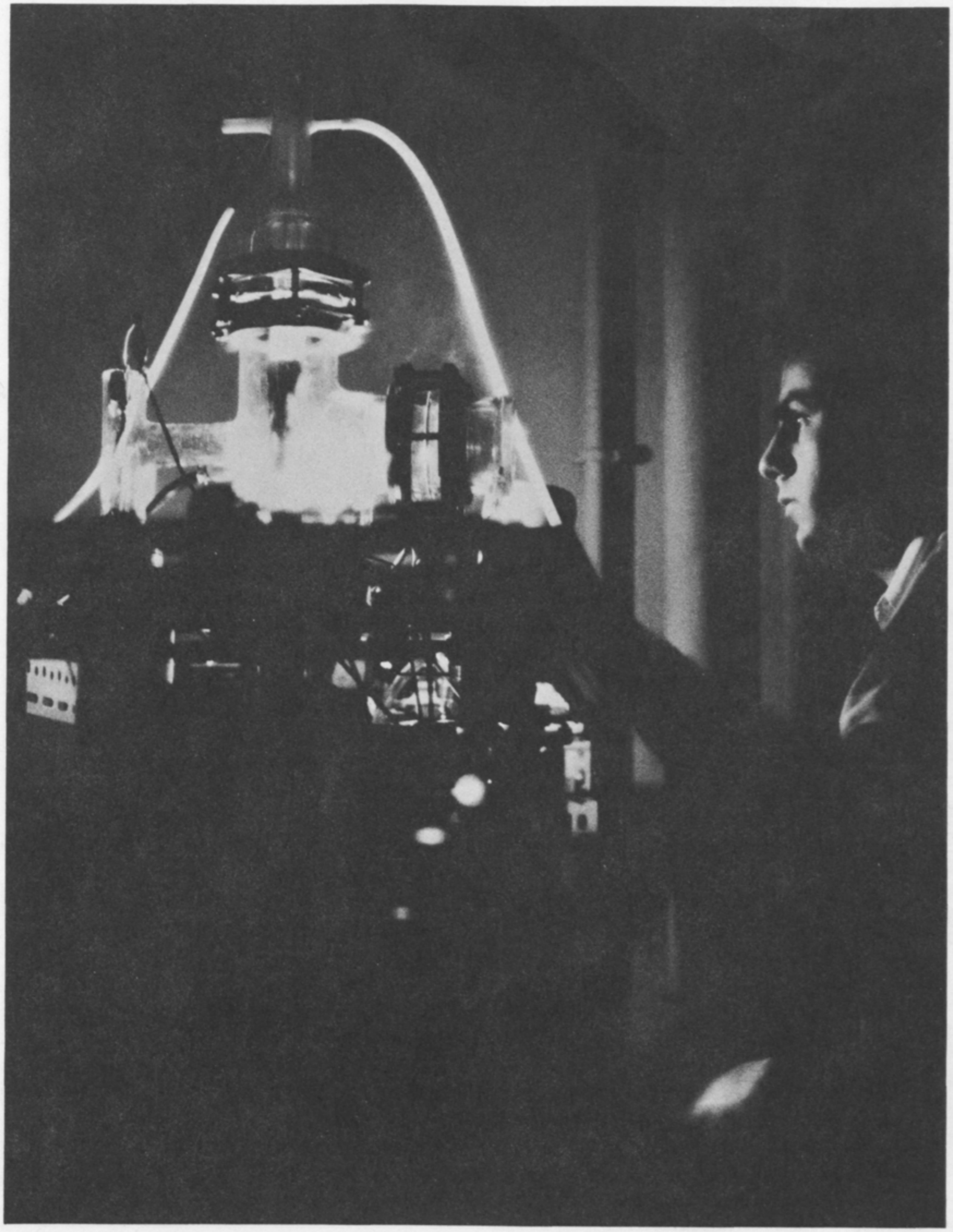
studies the idea emerged that the crystals contained some defect which could be easily moved through the crystal and which when it had traversed the whole of the slip plane produced a quantum of deformation. Conceptualization of the form of this defect emerged almost simultaneously in several different places. Probably the major contributions to the earliest theory were made by G. I. Taylor and Egan Orowan. In 1934 both published descriptions of a hypothetical defect which would account for the behavior of the single crystals. This defect, a line of defects through a crystal, has come to be known as a "dislocation."

MATERIALS AND THE ELECTRON MICROSCOPE

Much theorizing occurred about "dislocations" without very much direct experimental support until it was found possible to utilize the electron microscope to study such defects. Only a little more than ten years ago the first foils of an opaque solid were produced which were sufficiently thin to be penetrated by electrons. The crystalline defects in these thin films scatter the electrons and in this way the location of the defects is revealed. Since the perfection of this technique, the rate of accumulation of knowledge of structure on this scale has been staggering. Many new and in some cases unthought of types of defects have been revealed, and the geometry and properties of many defects have been studied in much detail. It is now possible to apply tensile stresses or to heat and cool a specimen over a wide range of temperature while it is still in the electron microscope. In spite of the fact that these microscopes are expensive, they have become indispensable to the study of structure. At Cornell our central electron microscopy facility is serviced by the Materials Science Center.

FIELD-ION MICROSCOPY AND CORNELL

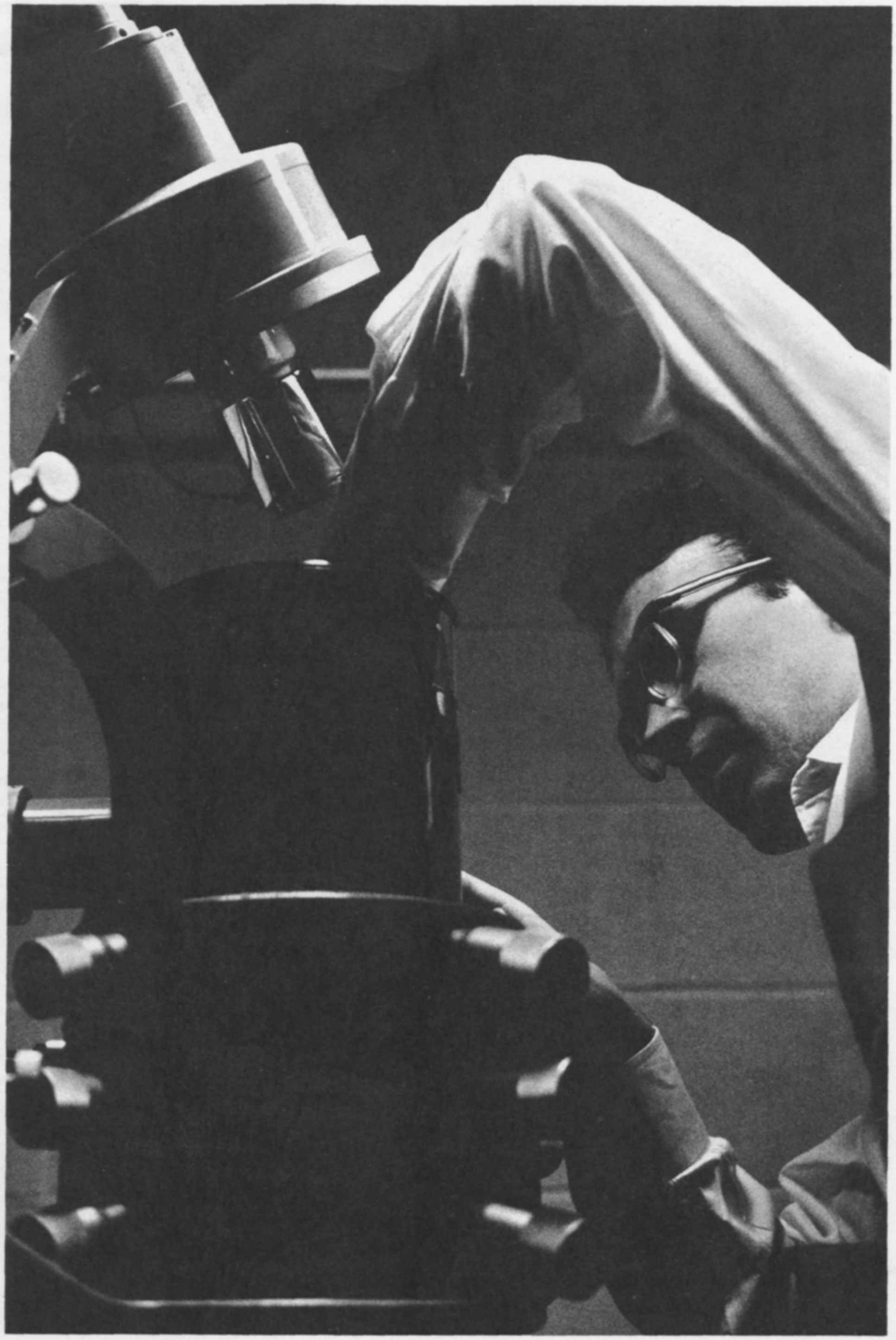
The limit of resolution of the techniques in general use for materials examination is a crystalline defect involving probably at least a few atoms. A concerted effort is being made to find and develop new techniques of structure investigation which will provide even greater resolution than this. By far the most promising of the techniques which are not yet fully developed is field-ion microscopy. It is believed that defects which involve only one atom, such as a vacancy in a crystal lattice, can be studied by this technique. Some success has already been achieved and it is likely that a major advance will occur within the next two or three years. Cornell is in the forefront of field-ion microscopy. Professor T. N. Rhodin has been concerned with developing the technique through an understanding of the physics involved, and with exploring possible applications in surface physics and chemistry. Professor D. N. Seidman is leading a group who are building a field-ion microscope laboratory with the object of developing the technique and its applications to the study of point defects in solids. This latter work is being carried out in close collaboration with Professor R. W. Balluffi and his students who have for some time been studying point defects by a variety of physical techniques.



Professor David N. Seidman adjusting an experimental field-ion microscope for the study of point defects in solids. Field-ion microscopy is one of the most promising of the techniques, not yet fully developed, which should provide for finer resolution than multiple atoms.

STRUCTURES AND CHANGING PROPERTIES

Of course the study of structure is only a means to an end. It is necessary to understand how the structures are developed or modified by the numerous chemical, thermal, or mechanical treatments the material may undergo during its manufacture. An equally important part of the activity of the materials scientist is to understand how the engineering properties such as the yield strength, the work hardening, the fracture properties, the electrical and magnetic properties are affected by changes in the structure either on a coarse or a very fine scale. A good example of this activity is the work Professor G. V. Smith is doing in studying details of the structural changes occurring in dilute alloys of iron made from materials of high purity when these alloys are subjected to various hot and cold rolling treatments and are subsequently annealed. Obviously it is important that we understand the structural changes in detail and it is perhaps surprising that our knowledge in this area is still inadequate. Unfortunately, the changes which are of greatest importance take place on a fine scale and in an extremely subtle manner. A different approach to the development of structure is that taken by Professor E. Scala and his group who are working on the production of structure by synthetic means. They decide what kind of structure would produce the most beneficial property and then devise ways of producing such a structure. This type of activity has led to the development of composites, usually fibers of one material dispersed in a matrix of another.



Dr. Humphrey Bowden, research associate, regulating the gun of an electron microscope, an instrument which has become indispensable in the study of materials.

HIGH PRESSURE, FRACTURE, AND ELECTRICAL EFFECTS

We are accustomed to thinking of the structures which are of importance as being those which are formed at atmospheric pressure. However, many interesting changes in structure can be produced by subjecting materials to high hydrostatic pressures. This technique has extended our knowledge of how structures are developed and it has enabled us to obtain a better understanding of the interaction between the structure and some of the properties. At Cornell, Professor A. L. Ruoff supervises the operation of our well-equipped high pressure laboratory.

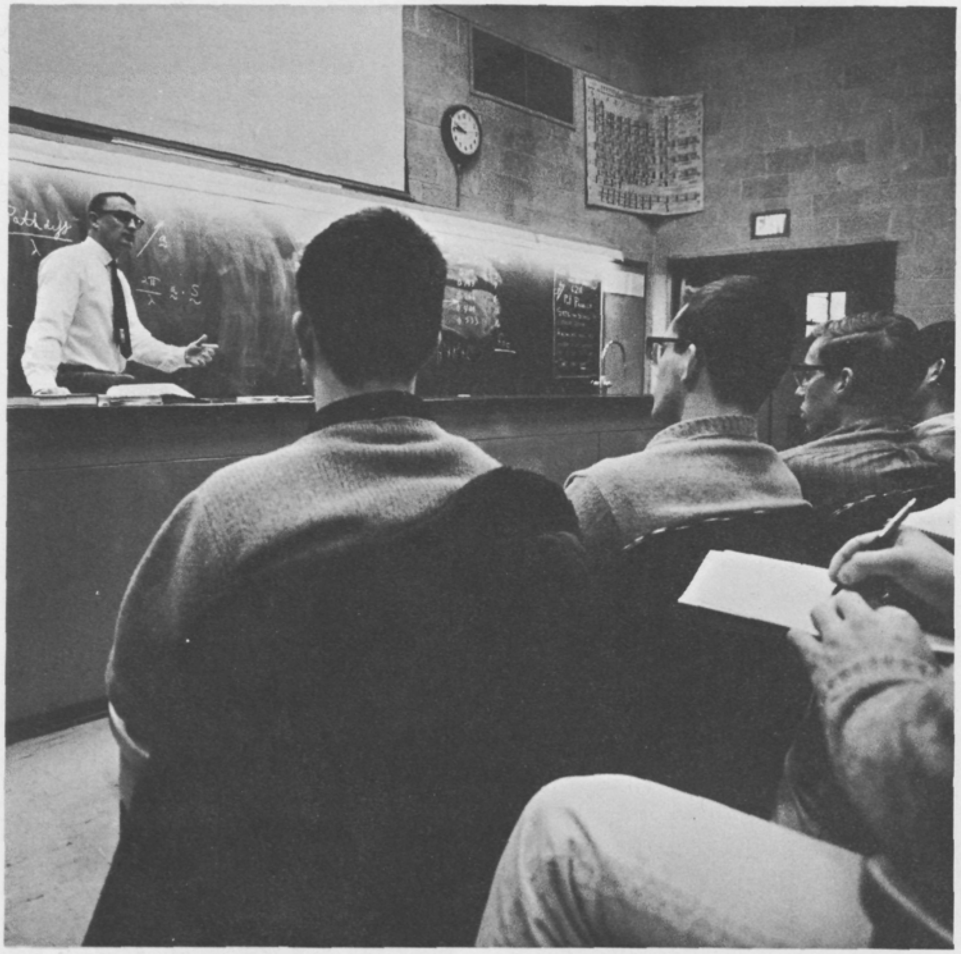
Many mechanical applications of materials are limited not by strength considerations but by the onset of rapid fracture. This applies to many nonmetallic as well as to metallic materials. Problems of fracture are being studied by Professors H. H. Johnson and Che-Yu Li, and a recently organized mechanical properties laboratory will greatly add to the efficiency of their work. The new laboratory will contain a 50-thousand pound tensile machine with a sophisticated electronic control system that will enable the strain rate and the loading rate applied to the specimen to be programmed, recording various experimental measurements with great precision. The interesting work on the physics and chemistry of surfaces and interfaces which is being carried out by Professor J. M. Blakely and others should interact profitably with that being carried out on fracture and on structural changes involving interfaces.

Of course, the work on properties of materials is not confined to mechanical properties. The effect of various structural parameters on electrical and magnetic properties of solids is being studied by Professors John Silcox and W. W. Webb who are particularly interested in examining the sensitivity of superconducting materials to defects in the crystal lattice.

THE OUTLOOK AT CORNELL

Thus at Cornell we have substantial and successful activity underway in all the important traditional and emerging areas of materials science. This research activity is being carried out by young men who are rapidly establishing themselves in the forefront of their profession and who are supported by an organization which has been able to provide first-rate equipment and laboratories. At a time of such rapid development it is hard to realize that the whole materials science effort at Cornell is still in a formative stage. Some semblance of stability should be reached in the next year or two, but meanwhile there are still important gaps in our effort to be filled and a few omissions of personnel and equipment to be made good.

The academic divisions within most universities are those which were adopted long ago. In engineering there have been some new technologies taught in universities during the last forty or fifty years but these have largely been confined to rather specific applications. It is easy to define the activities within departments of metallurgy, ceramics, or nuclear engineering, but materials science is different in concept from these. It represents an attempt to



establish a completely new engineering discipline within the university. By its very nature it is interdisciplinary because it must rely upon knowledge fed into the subject by physics, chemistry, mathematics, and the established engineering subjects. It must be concerned with a variety of materials, perhaps the most important from an engineering point of view being plastics, ceramics, glasses, metals, and composites.

There have been numerous conferences, attended by both university and industrial engineering scientists, devoted to defining precisely the essential nature of materials science. It appears that the usefulness of this kind of discussion has passed the optimum and the time has come to demonstrate by deeds what materials science is all about. By our research and teaching in the next ten years Cornell's Materials Science and Engineering Department will play a major part in bringing the subject from its present state to an established university discipline.

Walter S. Owen, Thomas R. Briggs Professor of Engineering and Director of the Department of Materials Science and Engineering, came to Cornell in January from the University of Liverpool. He teaches in the areas of mechanical properties and the physical metallurgy of steel.

At Liverpool Dr. Owen was Dean of the Faculty of Engineering Sciences and the Henry Bell Wortley Professor of Metallurgy. He was born and educated in Britain (B.E., M.E., and Ph.D. degrees from Liverpool, all in metallurgy) and first came to the U.S. in 1951 as a Commonwealth Fund Fellow at M.I.T. He returned to Liverpool in 1957 but continued to contribute to research here, notably at Wright-Patterson Air Force Base, home of the U.S. Air Force Institute of Technology.

In England Dr. Owen was a consultant to the United Kingdom Atomic Energy Authority, the International Nickel Company, Ltd., the English Electric Company, Ltd., and Richard Thomas and Baldwin, Ltd.; a member of the Grants Committee of the Council for Scientific and Industrial Research and the Metallurgical Research Council; and chairman of the Physical Metallurgy Group of the British Iron and Steel Research Association. He continues as editor of the physical metallurgy series in the Commonwealth Library of Technology and has authored many publications.

Professional memberships in the U.S. are Sigma Xi, the American Society of Metals, and the American Institute of Mining and Metallurgical Engineers.

Three engineering sciences are required in the core curriculum for all Cornell engineers. One of the three may be materials science. Here, Professor Arthur L. Ruoff lectures to sophomore engineers on this subject.

MECHANIC ARTS TO MATERIALS SCIENCE

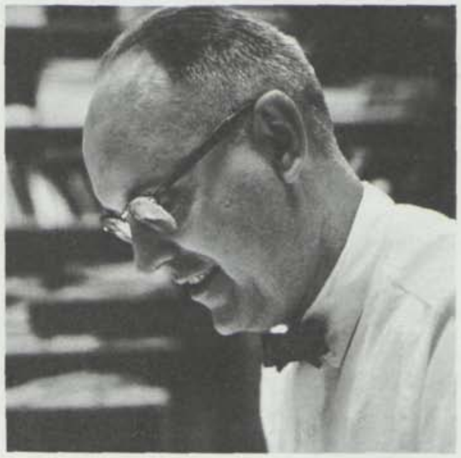
By Malcolm S. Burton

Although Materials Science and Engineering has existed as a separate department at Cornell for less than two years, involvement in the study of materials can be traced back to the early years of the University. Mechanic arts courses and facilities similar to the cast metals laboratory illustrated in 1885 in *Scientific American* were outstanding at the turn of this century and served as models for laboratory studies in engineering materials for many other Colleges. Cornell's interest in materials behavior remained largely an applied laboratory activity, reflecting the level of technology, until a more fundamental interest in materials developed during the second quarter of this century.

A most important influence leading to a serious study of materials at Cornell developed during the thirties when microscopy came of age. Professor Clyde W. Mason (see p. 30), first in Cornell's Department of Chemistry and later in the School of Chemical and Metallurgical Engineering, became an effective force in the development of a materials science discipline through his interest in the microstructural approach to the study of materials properties. His metallography courses developed the concept that properties of materials are related to and controlled by their structure. These courses formed the nucleus from which modern instruction and research in materials grew. Through his activities a number of Cornell graduates became eminent metallurgists.

During World War II, S. C. Hollister, Dean of Engineering, recognized the ascending importance of the study of materials in engineering, and sought the interest and aid of Mr. Francis N. Bard of Chicago, a Cornell Mechanical Engineer of the Class of 1904, prominent in the metals industry. In 1946 Mr. Bard endowed the professorship in applied metallurgy that bears his name. At the time of the announcement of the professorship Mr. Bard suggested two basic directions for a modern metallurgy program: "The inspiration and development of keen, productive, and scientifically minded men in the field—and the undertaking and accomplishment of metallurgical research of the highest order."

In 1946, the School of Chemical Engineering extended its range of interests and became the School of Chemical and Metallurgical Engineering. A faculty was recruited and a curriculum in Metallurgical Engineering was established, its first graduates receiving diplomas in 1950. During this same period following the war, two new departments were formed—Engineering Physics, and Mechanics and Materials—both of which furthered the study of materials. Teaching and research activities in materials science



In October, 1885, engravings on the cover of Scientific American *featured these scenes of Cornell's Sibley College of Engineering. The forge shop and the foundry are illustrated at the left and the right, respectively, of the Sibley College buildings at the center of the page.*

and materials engineering expanded along these three fronts, chemical and metallurgical engineering, engineering physics, and mechanics and materials, until 1962 when Dean Dale R. Corson, now Provost of the University, acted to draw together into one department the faculty from the various divisions of engineering interested in materials studies. This department, Engineering Physics and Materials Science, continued until the formation of a separate Materials Science and Engineering Department by Dean Andrew Schultz, Jr. in January 1965.

Mr. Bard, who had already established the Bard Professorship in 1946, also provided a modern building equipped for the study of materials which was first occupied in August 1963. Bard Hall houses a major portion of the activities of the Department of Materials Science and Engineering, providing excellent facilities for both undergraduate and graduate teaching as well as for research in materials.

Further impetus for progress in Cornell's materials program came with the formation of the Materials Science Center in July, 1960. The Center was established to improve graduate instruction and research in materials and to increase the number of graduates for the American economy. With grants from the Advanced Research Projects Agency of the Department of Defense, the Center has become an important source for financial assistance and equipment for graduate students on the campus engaged in the study of materials. The Center has made it possible for the faculty to extend their interests in numerous new areas of materials activity.

Figure 1

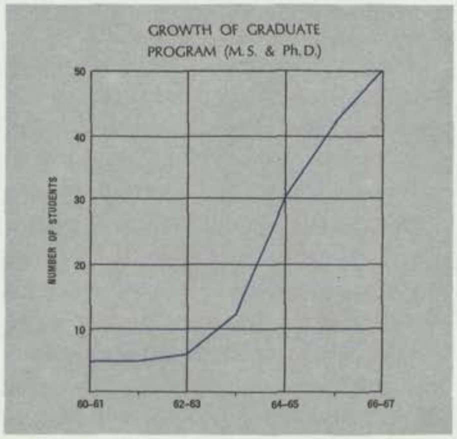
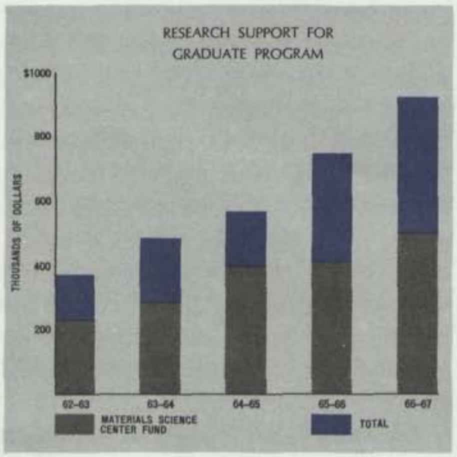
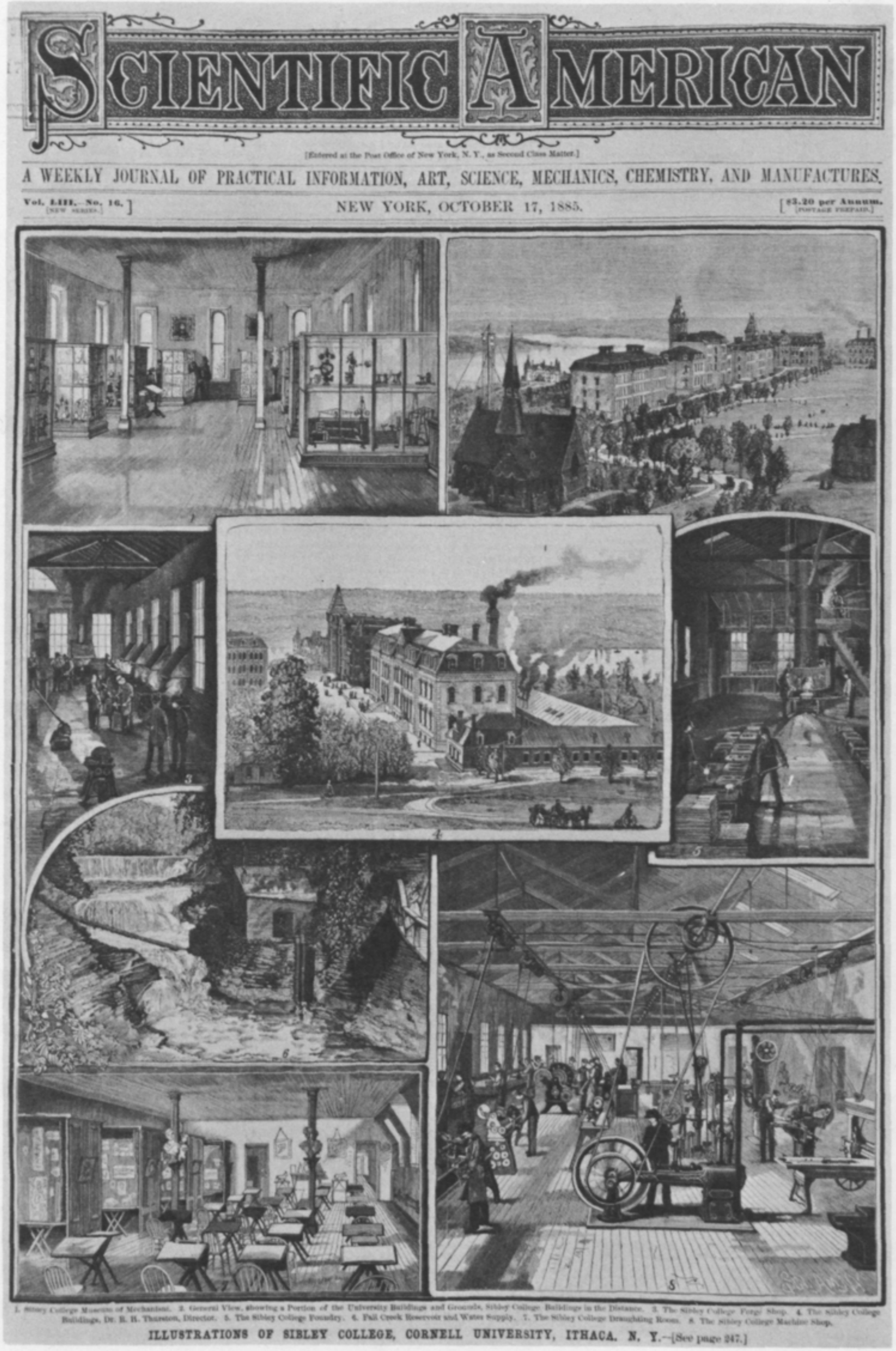


Figure 2



As can be seen in Figures 1 and 2, graduate teaching and research has undergone remarkable expansion in the past six years. Graduate study in materials essentially did not exist in 1950, involved only a few students in 1960, and increased to over forty students in 1965–66. Research support has increased from a few thousand dollars annually in the middle fifties to nearly one million at present.

Development of courses and curricular over the past century has reflected the changing philosophy of the faculty.



SCIENTIFIC AMERICAN

[Entered at the Post Office of New York, N. Y., as Second Class Matter.]

A WEEKLY JOURNAL OF PRACTICAL INFORMATION, ART, SCIENCE, MECHANICS, CHEMISTRY, AND MANUFACTURES.

Vol. LIII.—No. 16. [NEW SERIES.] NEW YORK, OCTOBER 17, 1885. [$3.20 per Annum. POSTAGE PREPAID.]

1. Sibley College Museum of Mechanism. 2. General View, showing a Portion of the University Buildings and Grounds, Sibley College Buildings in the Distance. 3. The Sibley College Forge Shop. 4. The Sibley College Buildings, Dr. R. H. Thurston, Director. 5. The Sibley College Foundry. 6. Fall Creek Reservoir and Water Supply. 7. The Sibley College Draughting Room. 8. The Sibley College Machine Shop.

ILLUSTRATIONS OF SIBLEY COLLEGE, CORNELL UNIVERSITY, ITHACA, N. Y.—[See page 247.]

In the early days of the College, engineering instruction was principally in engineering technology and mechanic arts. More recently, an increasingly comprehensive understanding of atomic and molecular structure and generation of new knowledge of materials has been the basis for our teaching and research program. Courses of a decade ago were highly descriptive and oriented to the existing level of industrial practice. Today's curriculum reflects the broader and deeper foundation in basic sciences, engineering sciences, and mathematics necessary if new contributions are to be made to this dynamic technical activity. Today we strive to provide a materials education rather than a training in metallurgical phenomena. Comparison of the curriculum in Metallurgical Engineering of 1947 to that of Materials Science and Engineering in 1966 reveals this shift in emphasis. Worth mentioning here is the fact that beginning with 1947, there has not been a single year in which the curriculum remained the same.

This year our undergraduate students may choose a program specially oriented to materials science or a broader curriculum covering both materials science and materials engineering. Why this shift in emphasis? The study of materials has emerged in the mid-sixties as a new discipline at the very frontier of engineering, upon which many future industrial programs will depend. Although some materials engineers act as consultants and advisers to other engineers on selection of materials for particular applications, this is not their major function. Rather, they are concerned with broad questions of materials properties and use; with generation of greater knowledge and understanding

"...beginning with 1947 there has not been a single year in which the curriculum remained the same."

1

2

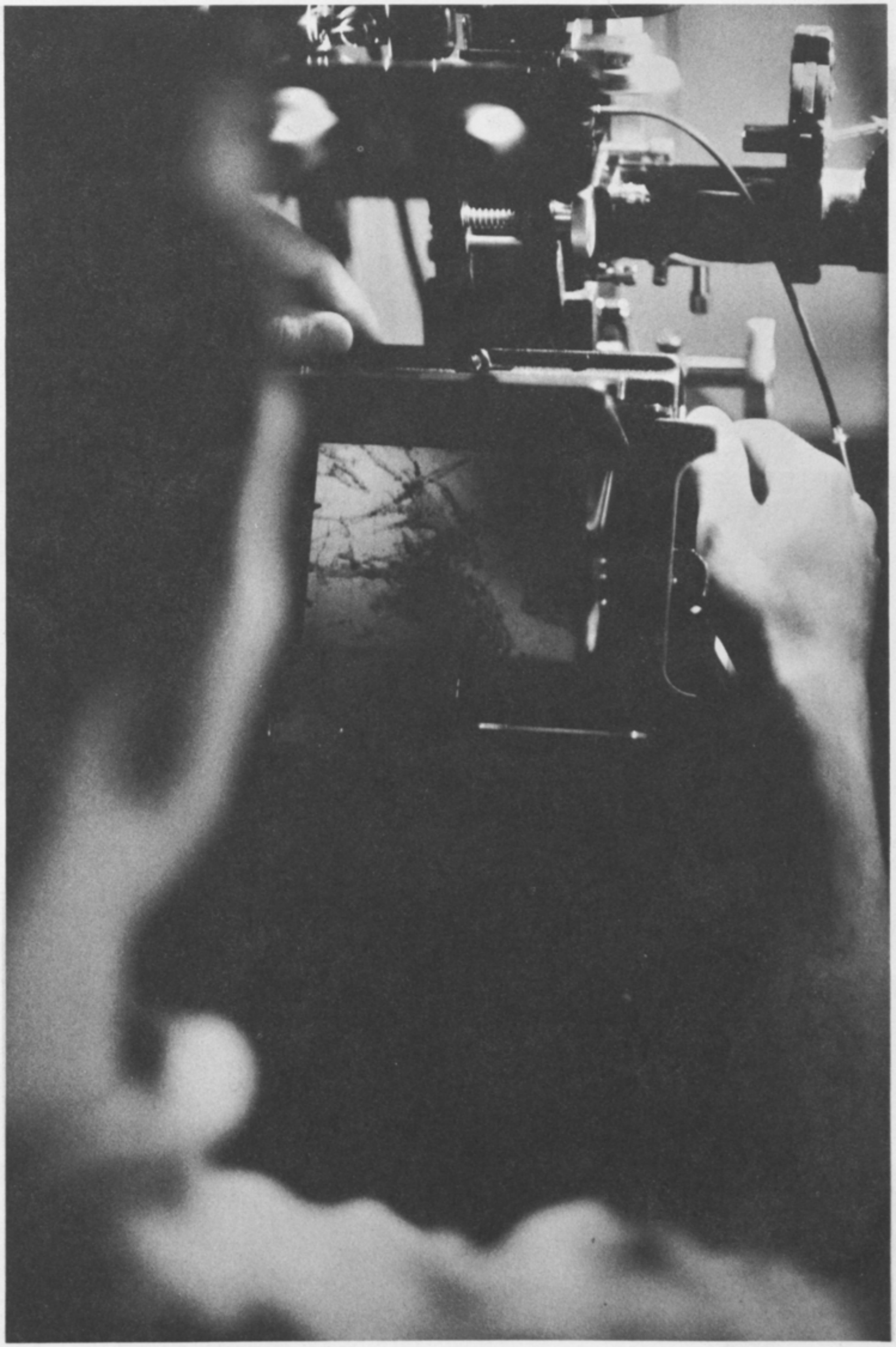
1. The Cornell foundry at the turn of the century.

2. The modern counterpart, the metals working laboratory located in Bard Hall.

3. A student focusing a metallographic image on the metallograph's glass screen.

of new materials; with the processing of materials having superior properties into particular sizes and configurations. As is well known, a more efficient gas turbine usually means that an improved blade material has been developed. Improvement in the strength-weight ratio property of a material may indicate that a new configuration has been conceived, requiring new forming and fabricating techniques (e.g. adhesive bonding of honeycomb structures). Improved processing is usually developed and controlled by materials engineers.

While the direction that materials studies will take in the future is not clear, it is likely that it will continue to be based on the relationship of structure to properties. Nearly all research in the Department is concerned with this relationship. Increase in graduate activity indicates that important advanced concepts are coming to the fore, that materials study is a definable discipline, and that advanced study is required for effective work in the field. Graduate students come from various backgrounds; metallurgists study side-by-side with physicists, chemical engineers, physical chemists, mechanical engineers, and others. While much of the rapid progress in materials has been made with metals, better understanding in recent years of the nature of materials has nucleated fundamental study of non-metallic materials. The goal of the research program is knowledge that will allow the synthesis of tailor-made materials; the goal of the teaching program is to provide each student with the best possible educational background for effective work throughout his career. The Department of Materials Science and Engineering is making excellent progress toward these goals.



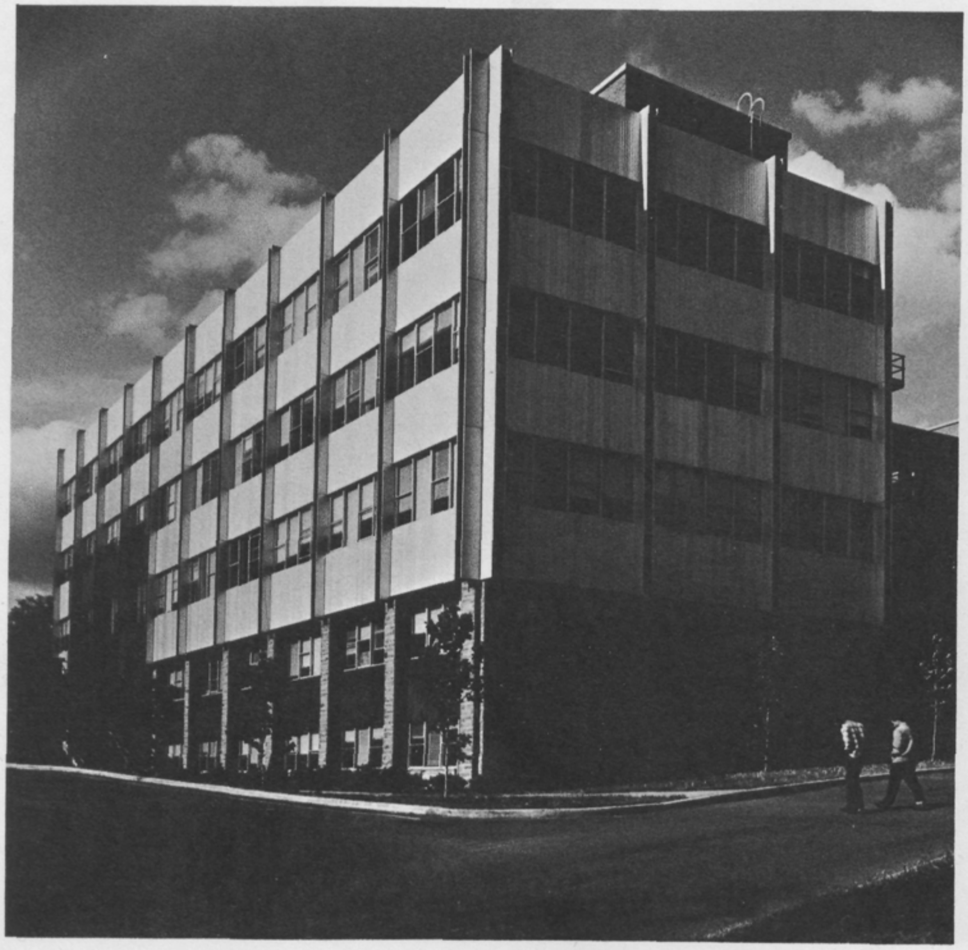
3

Malcolm S. Burton, Professor of Materials Science and Engineering and Assistant Director of the Department, is a native of Boston. He received the B.S. degree at Worcester Polytechnic Institute in 1940 and the S.M. degree at M.I.T. in 1943. He began teaching as an assistant in mechanical engineering at M.I.T., became an Assistant Professor of Metallurgical Engineering there, and then joined Cornell's faculty in 1946. At Cornell he became Associate Professor in 1949 and Professor in 1956.

During 1964 Professor Burton was Assistant Director of the Department of Engineering Physics and Materials Science, and Chairman of the Materials and Metallurgy faculty. From January 1965 until January 1966 he was acting Director of the Department of Materials Science and Engineering. His industrial experience includes consulting with Bell Telephone Laboratories, the du Pont Company, Woodbury Letterhead Company, Ford Motor Company, and the Cornell Aeronautical Laboratory. He is author of the textbook Applied Metallurgy for Engineers *and numerous scientific papers.*

Professor Burton is on the Core Curriculum Committee of the College of Engineering, and has served on the Engineering Policy Committee and the Executive Committee of the Materials Science Center. He is a member of the American Institute of Mining and Metallurgical Engineers and of the Executive Committee of the Southern Tier Chapter of the American Society for Metals.

VANTAGE



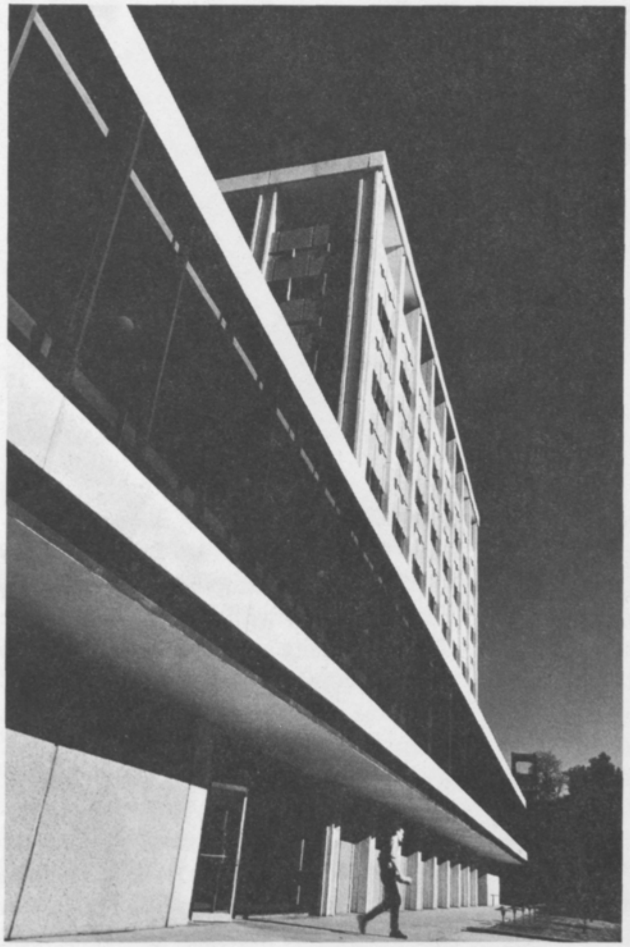
Bard Hall, a gift of Francis Norwood Bard, a Cornell Mechanical Engineer of the Class of '04, was dedicated in 1963. It contains approximately 45,000 square feet of floor space on its six floors and was designed to provide the College of Engineering with teaching and research facilities in Metallurgical Engineering, now the Department of Materials Science and Engineering. Before its completion, the plans were executed to encompass research facilities for the Materials Science Center, available to any personnel of the University working in materials science.

Mr. Bard's interest in materials is natural, for he grew up in a steel mill atmosphere. His father organized the Indiana Iron Company and later participated in the organization of Republic Steel. The younger Bard was first a bolt threader and then a roll turner in a bar mill. After his graduation from Cornell he began his industrial career with the Platt Iron Works in Dayton, Ohio, and went from there to Allis-Chalmers Manufacturing Company where he designed steam turbines. In 1908 he joined his father in the management of the Norwell Manufacturing Company in Chicago.

A small research company purchased by the two Bards developed into the Barco

Manufacturing Company of Barrington, Illinois, makers of flexible ball joints, which were adapted first to railroad and locomotive performance, and are now used in aviation and missile service. Mr. Bard served as president of this company for more than fifty years before selling it in 1962. He has been active in several other corporations and has wide civic and political interests. He has operated an extensive ranch in Arizona where he developed the distinctive "Barzona" type of cattle.

A blending of stone, brick, and metal, the exterior of Bard Hall is a visually pleasing transition from the predominantly brick exterior of Thurston Hall to the more contemporary appearance of the other buildings on Cornell's modern Engineering quadrangle. The interior, designed for both undergraduate instruction and graduate research, contains a high-ceiling area equipped for processing metallic and non-metallic materials. The laboratory complex, in addition to the Edward Bausch Laboratory of Metallography given by the Bausch and Lomb Company, includes facilities for various methods of investigating the structure of materials. Equipment is available for physical, mechanical, and general metallurgy. Since many of the studies undertaken



in Bard Hall involve elevated temperatures, liberation of heat, and the handling of obnoxious or dangerous products, the building houses extensive apparatus for the control of these elements.

Complementing Bard Hall's facilities for the Materials Science Center are the main laboratories and administrative offices of the Center in the new Clark Hall of Science dedicated last October. This building is named for W. Van Alan Clark, who with his wife gave $3 million toward its cost. Like Francis Bard, Mr. Clark, '09, is a Cornell Mechanical Engineer. Two days after graduation he went to work in the Engineering Department of the Consolidated Gas Company in New York and then on to Brooklyn Union Gas Company. After his marriage to the former Edna McConnell, he joined her father in the perfume and cosmetic company which later became Avon Products. In 1942 he became Chairman of the Board of Avon and is now honorary chairman. Hays Clark, one of his three sons and also a Cornellian, is President of Avon, International.

Photos on this page are of the new Clark Hall of Science. All Vantage *photos by David Ruether.*

AN EYE AND EAR TO SPACE: The Man Who Developed Arecibo

By K. Toby Clarey

In this era of emphasis on automation, it is refreshing to meet such a man as Dr. William E. ("Bill") Gordon and remember that it is still the engineer, the man, who is responsible for making possible most of our modern scientific and technological marvels. One of these marvels is Cornell's Arecibo Ionospheric Observatory, the world's largest radar-radio telescope, at Arecibo, in Puerto Rico. Dr. Gordon, the Walter R. Read Professor of Engineering at Cornell, was largely responsible for this engineering achievement. He has now been named Dean of Engineering and Science at Rice University in Houston. Dr. Gordon will continue a Cornell association through three Ph.D. candidates at Rice whose research will be undertaken at Arecibo.

William Edwin Gordon's biographical sketch reads like a synopsis for the legendary American success story, and the man himself bears out the image, perfectly "cast" for the part. Tall, lean, gracious, and very human, this Professor of Electrical Engineering speaks warmly of his early experience as a ninth grade teacher. He recalls his students "on the edges of their seats, spellbound at the simplest of experiments." His mother had been a teacher, and this, together with the depression years, pointed him toward nearby Montclair (N.J.) State Teachers' College, where he received his B.A. degree in 1939. Until 1942, when he earned his M.A. at Montclair, he taught mathematics, science, and physical education in New Jersey, at Montclair and Oradell High Schools.

World War II, however, changed Bill Gordon's future considerably. He enlisted in the Air Force in 1942 as a cadet in meteorology. During this period also he was an instructor in meteorology at New York University; research meteorologist at the Army-Air Force Weather Service, and meteorologist for the Office of Scientific Research and Development. In 1946 he was awarded the M.S. in Meteorology at New York University. It was while he was in the service that the effect of weather on radar first drew his interest: "We were seeing things that we weren't supposed to see on our radar screens . . . why was radar too short or too long?" He worked with a weather station operated by the Massachusetts Institute of Technology in Orlando, Fla., and then with a civilian group at The University of Texas studying radar and meteorological parameters. It was at Texas that he received his discharge from the Air Force with the rank of Captain. At Texas, also, Dr. Gordon met Professor Charles R. Burrows, former Chairman of Cornell's School of Electrical Engineering. "Charlie Burrows got me more deeply involved with the riddles of weather in radar, and through him I became interested in Cornell," he explains. Dr. Gordon became a research associate at Cornell in 1948, received his Ph.D. in 1953 and the same year was promoted to Associate Professor; he was appointed Professor in July of 1959.

In addition to heading the team of Cornell engineers who designed Arecibo, Dr. Gordon has an impressive list of affiliations. He was supervisor of Cornell's troposphere project, and of the radio astronomy and solar noise projects. He has been Chairman of the Joint Commission on Radio Meteorology

Dr. William E. Gordon, the developer of the Arecibo Ionospheric Observatory, stands on the catwalk that connects the 'big dish' feed arm support with the ground.

and was Chairman of the United States National Commission of the International Scientific Radio Union. He has been widely published, and has presented papers at the Joint Commission of Radio Meteorology in Brussels, at the Radar-Weather Conference in Montreal, and at the Radio-Wave Propagation Symposium in San Diego.

Dr. Gordon was a National Academy of Science-Research Council delegate to the General Assembly of the International Scientific Radio Union at Sydney in 1952, at The Hague in August 1954, and at Boulder in 1957, and he led the United States Delegation to London in 1960. He is a member of Sigma Xi; Phi Kappa Phi; Kappa Delta Pi; Tau Beta Pi; a Fellow of the Institute of Radio Engineers and Professional Group on Antennas and Propagation, and he is a Professional Member of the American Meteorological Society.

"The creation of scientific puzzles: Why does Venus move in a contrary direction? Observation of the rotation of the planets, the comparison of radar maps with optical maps, new pieces of knowledge, getting Arecibo itself built"– these are some of the many satisfactions that Dr. Gordon, not yet fifty years of age, enjoys.

Rice University has its own satellite program: Project Owl, a brainchild of the Rice Department of Space Science. In addition to space science, there are five other science departments and four engineering schools that Dr. Gordon will lead as Dean of Engineering and Science. He intends to teach one course per term and to supervise the research of several graduate students. "At Rice even President Pitzer teaches and directs graduate students," he comments. Dr. Gordon adds that he was impressed with the quality of the approximately 1,200 engineering and science students during a visit to Rice, at which time he stayed in their quarters and joined them at seminars.

Dr. Gordon says, "Texas has been described as an educationally developing state with a big gap in the middle which needs to be filled, but the state is making great strides in upgrading its program." He looks forward to fostering research at Rice.

The Gordon family liked living in the tropics during their Arecibo stay, and are delighted to be going again to a warm climate. They have purchased a swimming pool in Houston "surrounded by a house." Son Larry, married, has finished the fourth year of a five-year course in architecture at Rensselaer Polytechnic Institute. A daughter, Nancy, is a biology major at Jackson College, Tufts University.

Dr. Gordon's hobby is sailing. In Puerto Rico he had access to a 28-foot sloop in which he voyaged to the Virgin Islands. In Ithaca he made the most of Cayuga Lake, and now expects Galveston Bay to be a second home.

It is a long way professionally from Montclair State Teachers' College to the Deanship of Engineering and Science at Rice. Dr. Gordon made the journey a fascinating one, by way of Arecibo. The Cornell College of Engineering will follow with pride the future course of one of its gifted men.

AN EYE AND EAR TO SPACE

Engineering the Telescope

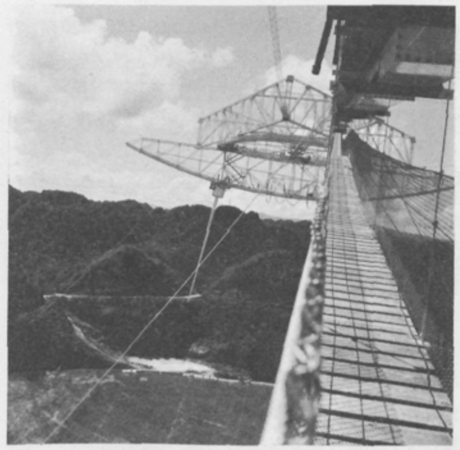
By Donald F. Berth

Take a basketball and cut off about one-third of it, making a bowl. Then imagine yourself to be the size of the head of a common pin situated at the bottom of the bowl, looking up at its rim. Roughly speaking this is the sort of sensation you would experience if you were looking up toward the rim of Cornell's Arecibo Ionospheric Observatory in Arecibo, Puerto Rico.

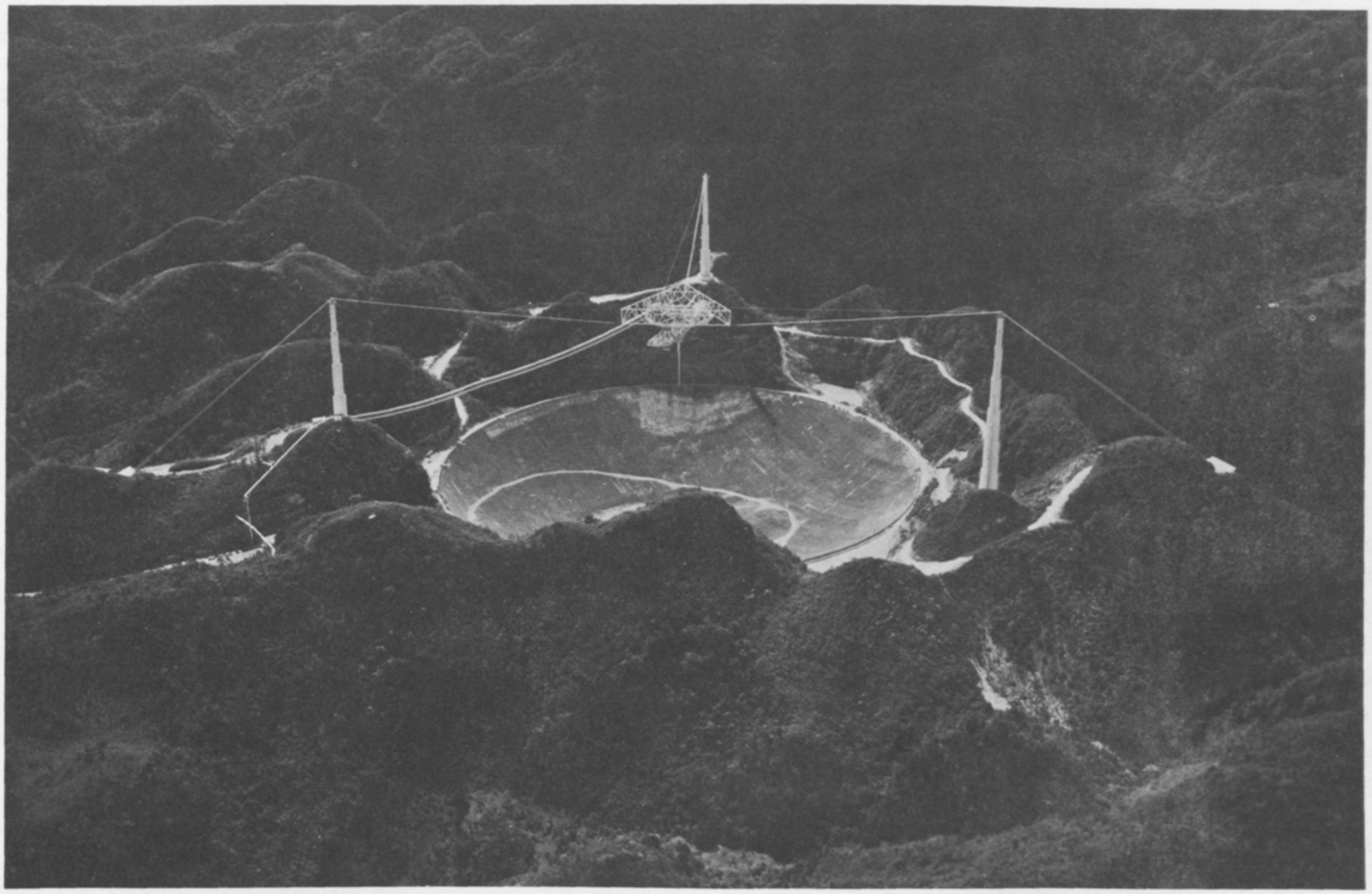
The Observatory's major facility is a large spherical reflector with a surface radius of curvature of 870 feet. However, since the reflector is only a portion of a ball, instead of a diameter of 1,740 feet, it is 1,000 feet across at its rim. This facility is both the largest known radio "ear" and "camera lens" in the world; and this big "ear" and "lens" system is oriented to space measurements and sustained observation of the chemical, physical, and dynamical properties that form the atmosphere and the objects it contains.

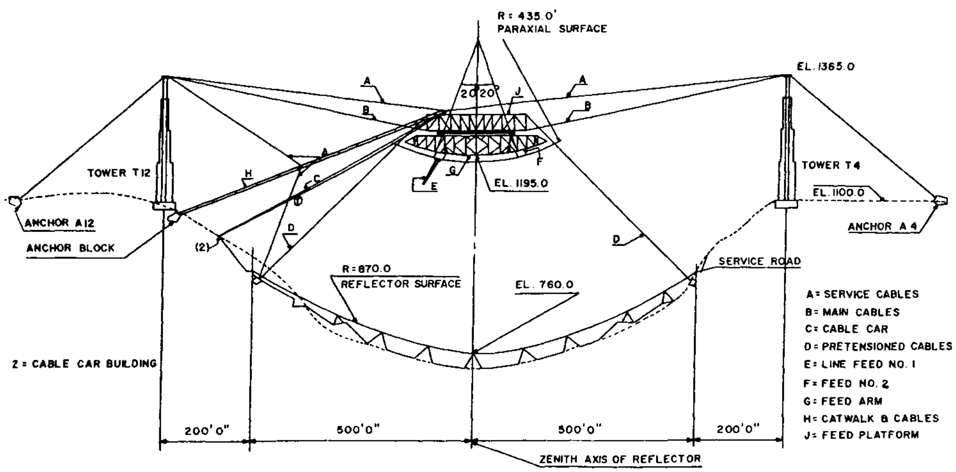
When functioning as a "camera" (or radar telescope) the instrument transmits a pulsed signal produced by a "feed," and receives between pulses that portion of the signal reflected back by electrons in the ionosphere or from the moon or planets such as Mars or Venus. When operating as an "ear" it listens to radio energy emitted by the sun, the planets, and distant celestial radio sources.

It was Dr. William E. Gordon's interest in atmospheric radio wave research (the scattering of waves by the free electrons in the atmosphere) that led him to conceive of an apparatus which could observe this behavior quantitatively. Basing his calculations on existing transmitter and receiver capabilities, he determined that a parabolic reflector 1,000 feet in diameter would utilize the upper limits of transmitter and receiver technology and make possible the measurement of atmospheric temperature, motion, and composition. The big question was whether such a large surface could be built. Dr. Gordon consulted two Cornell professors of structural engineering, George Winter and William McGuire. They concluded that such a structure was feasible despite the demanding requirements of surface accuracy, so affected by temperature variations and the structure's weight. Obviously a "wavy" lens would produce a "blurred photograph"; and an "ear" listening for faint noises could tolerate little structural variation. With Dr. Gordon, Professors Winter and McGuire decided that an earth-stabilized reflector, built close to the ground, would best meet the design criteria.

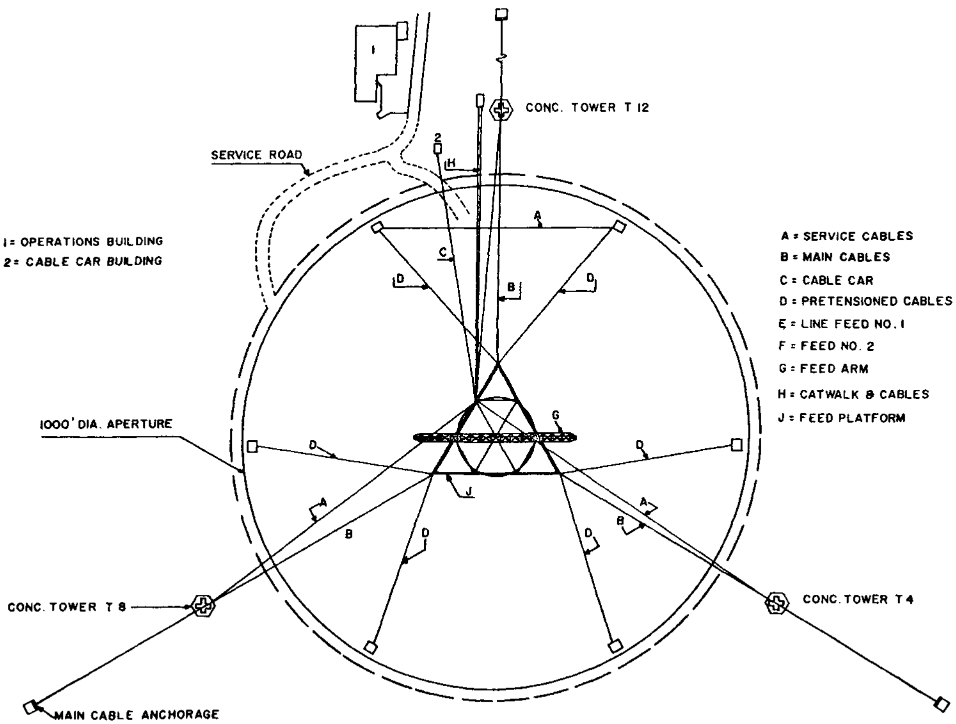


Having concluded that the reflector was structurally possible, Dr. Gordon approached another Cornell Engineering faculty team for assistance. Could a site be located in which such a reflector





ELEVATION



could be built—a natural bowl with a minimum of excavation and filling, and good drainage? The aerial photo studies group, headed by Professor Donald Belcher of the College's School of Civil Engineering, was asked to suggest potential sites near the equator. These sites had to fulfill several requirements: They had to be located where solar system objects pass more nearly overhead (the tropics); they had to be in a climate of moderate temperature changes, to reduce problems of structural expansion and contraction, and be removed from the electrical interferences of metropolitan areas or air routes.

With his knowledge of the surface of the earth, Professor Belcher suggested several possible locations that met these requirements. With the aid of aerial survey maps, the possibilities were weighed and then narrowed to a few locations, and on-site inspection of these few was made by Belcher and Gordon. A 125-acre site in Puerto Rico, 11 miles from Arecibo and the coast, and protected by surrounding hills, was chosen. It had been located originally by an aerial survey analysis of an area whose sinkhole topography was caused by the collapse of huge caves formed by the solution of limestone in water.

In 1958 the support of the Advanced Research Projects Agency of the Department of Defense (ARPA) was sought. ARPA was interested in the ionosphere, the medium in which many future scientific and military flights would be made. It was suggested that greater radar flexibility would result if the original fixed antenna design with a ± 2 degree scan was modified to introduce greater steering—or scanning—capability. Because the United States Air Force Cambridge Research Laboratories had nearly a decade's experience with steerable spherical reflectors of up to 10-feet-diameter serving as receiving antennas, their report enabled Gordon to design a more flexible steering system for directing and receiving signals within a 40-degree cone centered overhead. A spherical reflector was substituted for the earlier parabolic surface.

With ARPA support a contract for the construction was signed by Cornell and the USAF Cambridge Research Laboratories in November 1959. Construction began in June 1960, and the Observatory was dedicated November 1, 1963. Dr. Gordon directed construction and served as first Director of the Observatory until September 1965, when he returned to the campus as the Walter R. Read Professor of Engineering.

RECENT ACTIVITIES AT ARECIBO

Since the fall of 1963, part of the observing time has been used to calibrate the various components in the system and to determine operating characteristics, particularly the degree of accuracy of the observations. However, three major concurrent areas of study are presently being undertaken at Arecibo: One has to do with studies of electron density in the ionosphere; another is concerned with the properties and behavior of the moon and inner planets; the third uses the unsurpassed sensitivity of the antennas for radio astronomy.

It was Dr. Gordon's interest in radiowave interaction with the atmosphere—the scattering of radio waves by the "freed" electrons in the ionosphere—that led him to contemplate what would be the best optimum transmitter and receiver mechanism to study this phenomenon. About 30 miles up from the surface of the earth the thin atmosphere contains electrons that have been freed by solar radiation from their attachment to atoms of molecules of gases. The density of these electrons, and the resulting positive ions that are formed in the process of freeing an electron from its molecule, vary with height and with time.

At some height between 60 and 180 miles the electron density (number of electrons in a unit volume) is sufficient to reflect radio waves at frequencies of up to 10 megacycles. It is this reflective ability that enables us to have long-distance radio communication by reflecting the radio signal back to the ground one or more times as it travels around the earth from transmitter to receiver. Arecibo's powerful radar produces a profile of electron density by recording at different times the total power backscattered to the antenna.

While the free electrons scatter the radio waves, it is the positive ions that dominate the wave motions. Thermal velocities will be higher when warmer, lighter ions are present; thus temperatures of the charged particles and the ionic species may be deduced by comparing the transmitted frequency with those frequencies contained in the signal scattered back from a unit volume of the upper atmosphere. With this knowledge and data, temperature and ionic (atmospheric composition) profiles, both as a function of height, are being established at Arecibo. Such studies are contributing greatly to our understanding of the dynamics and chemistry of the ionosphere.

The planetary radar studies, the second of the present threefold study mission, have already "unearthed" new findings about the planets which suggest that the half-life of present-day astronomy textbooks will grow shorter. For example, it has been found that the planet Mercury rotates with an alternation of day and night rather than permanently sunlit on one half and night on the other half as had been believed on the basis of optical information. The planet Venus, named for a beautiful woman, has been found to rotate about its axis in a contrary direction from that of the other planets of our solar system. Why this is so is furnishing the Observatory with another interesting problem.

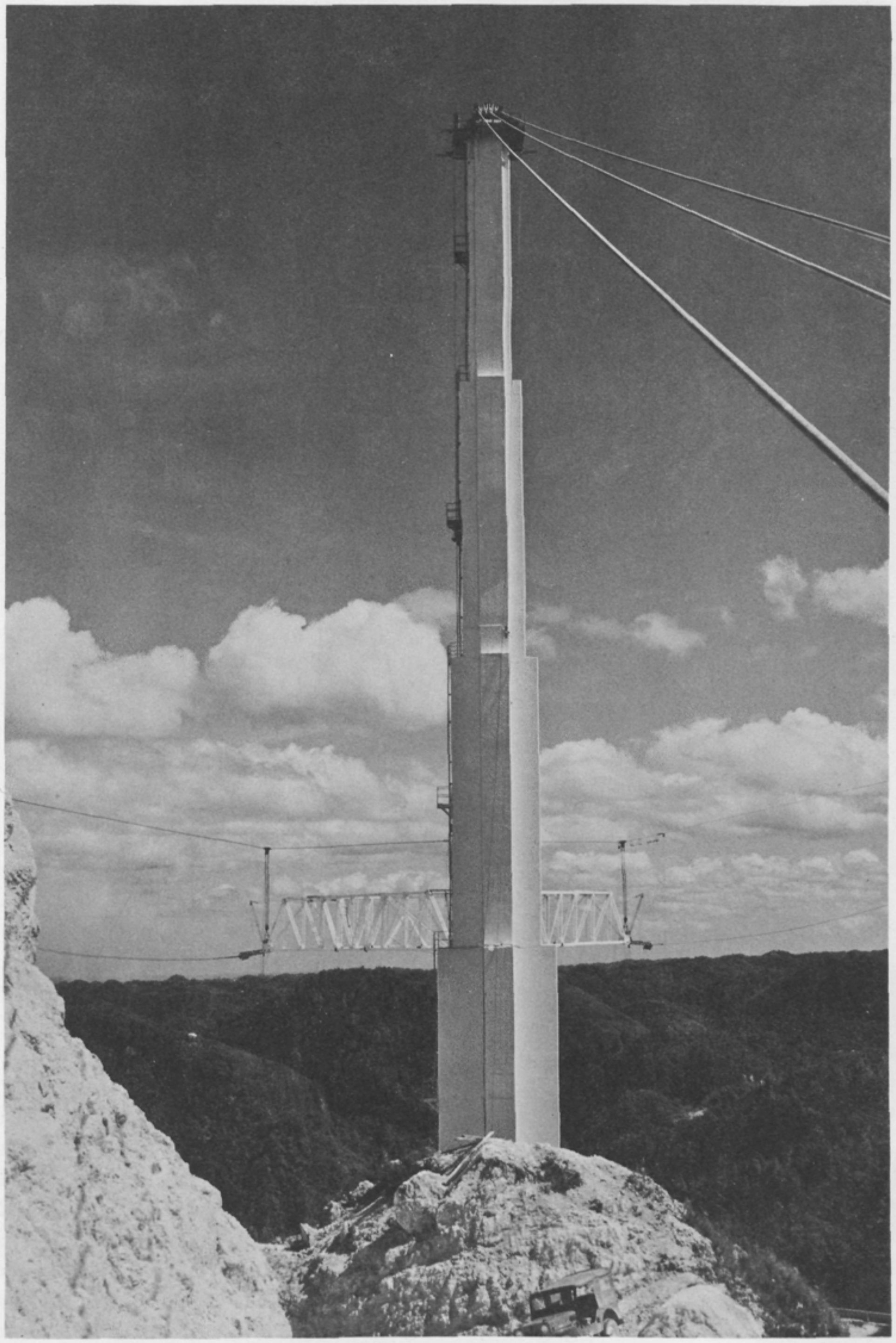
Another significant undertaking at Arecibo is the development of our first map of the surface of Venus, which can never be optically observed because of the planet's dense cloud cover. To develop techniques for this project, radar photos have been made of areas on the moon and then compared with optical photographs. Professor Ray Jurgens, a Ph.D. candidate under Dr. Gordon and now on leave from Clarkson College of Technology, is presently preparing the first surface map of Venus.

The third of the major areas of investigation at Arecibo is the instrument's use as a radio listening device. To date 3,000 radio sources in the universe have been located of which only about 100 have been identified optically. Among these are the sun, the moon, some planets, the Milky Way and other galaxies, and many nebulae. The design of the

Portion of one of the first radar maps of the moon's surface, overlaid upon an optical picture of the same area.

"dish" for radio astronomy combines great collecting area with an ability to resolve fine detail in the sky, both by day and night, and in any weather.

Since the beginning of its operations the Arecibo Ionospheric Observatory has been used by personnel from Pennsylvania State University, the University of Colorado, the University of Florida, Rice University, the University of California at San Diego, and the Air Force Cambridge Research Laboratory. "At any given time," Dr. Gordon comments, "the working group has an international flavor." Three Indians, a Frenchman, several Australians, a Swede, and a German are presently doing work at the Observatory. Its facilities are available to qualified engineers and scientists upon approval of a research proposal. Operating funds are provided by contract with the Air Force Office of Scientific Research with support from the Advanced Research Projects Agency, Department of Defense.



A view of one of the three towers which support the 525 ton feed arm.

The story is told of a cowboy who on seeing the Grand Canyon for the first time exclaimed, "Something happened here!" Anyone flying over Arecibo for the first time must surely feel a sensation of awe at the magnitude of this scene. Here something on a grand scale has happened, not because of the forces of nature and of time but because a few years ago a young man had an absorbing interest in weather and a scientific desire to explore some of the mysteries of weather's effect on forces which are changing the age in which we live. Not only did he have an idea but he also, with the collaborative efforts of other skilled professionals, pursued that idea through to its successful execution. Today man is pushing back the frontiers of space. And because "something happened" at Arecibo as a result of the vision and perseverance of Cornell engineers, the world's largest radar-radio telescope has come into being to play its part in the mighty space effort.

REGISTER

Bijlaard

Three men in the College of Engineering have been named Emeritus Professors by the Cornell University Board of Trustees, effective July 1, 1966. A brief biography of each, together with some of his professional accomplishments, is below.

■ *Paul P. Bijlaard,* Professor of Theoretical and Applied Mechanics, Emeritus, came to Cornell in 1949 as Associate Professor of Structural Engineering. A native of Holland, Professor Bijlaard received the Civil Engineering degree at Technical University, Delft, in 1920. After graduation he went to Indonesia to aid the government there in the construction and rebuilding of railroads. During this assignment he devised a unique cantilever method of erection for a new type of truss bridge that eliminated the need for costly falsework and saved the Department of Bridges and Structures of the State Railways one-third of the original cost estimate.

In 1928 at the age of twenty-nine Professor Bijlaard began his teaching career as a full professor of bridge and structural engineering at the Technical University of Bandung, Netherlands East Indies. During World War II he was captured by the Japanese and interned in a concentration camp until September, 1945. His experiences at this time directed his attention toward aircraft and missiles, an interest he was later to pursue as a consultant to the Cornell Aeronautical Laboratory.

Professor Bijlaard returned to his Alma Mater in 1946 and was Professor of Mechanics at Delft from 1947 to 1949. He and Mrs. Bijlaard, a native of Indonesia, came later to the United States to visit a daughter, and during this visit he decided to join the Cornell faculty. In 1951 he was appointed a full professor of structural engineering.

During his long teaching career Professor Bijlaard has served as technical consultant to several engineering enterprises that have earned him an international reputation. He likes to work at home, and Mrs. Bijlaard often assists him in his computations. She is an accomplished artist and their home in Ithaca contains many beautiful examples of her work in several media.

While Professor Bijlaard's investigations have been carried out on a theoretical basis, his theories of buckling of plates and shells and his method of split rigidities to permit solution of complicated buckling problems have been conclusively verified in tests by both government and private agencies. He has served as consultant to the Netherlands Railways of Holland; Bell Aerosystems; Curtiss-Wright; the U.S. Army Corps of Engineers; Brookhaven National Laboratory; Radio Corporation of America; Babcock and Wilcox; Blaw-Knox; Amman and Whitney; Shell Oil; Arabian American Oil, and others.

Early this year Professor Bijlaard was unanimously elected a Fellow of the New York Academy of Sciences, the citation reading "for outstanding recognition for scientific achievement and promotion of science." In 1941 Queen Wilhemina conferred on him her country's highest decoration, Knight of the Order of the Netherlands Lion. He is author of more than one hundred publications in English, French, German, and Dutch. He is a member of Tau Beta Phi, Chi Epsilon, Sigma Xi, and Phi Kappa Phi.

■ *Clyde W. Mason,* Professor of Chemical Engineering, Emeritus, was born in Watertown, South Dakota, and received the Bachelor of Arts degree at the University of Oregon in 1919. He entered Cornell as a Ph.D. candidate in 1920 and was awarded the doctorate in February 1924. During the early

Mason

McLean

twenties he worked as a Hecksher Research Fellow on structural color in birds and insects.

From 1920 until 1942 Professor Mason was with the Department of Chemistry. As a graduate student he was a teaching assistant; in 1924 he was promoted to instructor; in 1928 he was made Assistant Professor; he became Professor in 1940. In 1942 with the completion of Olin Hall and the establishment of the School of Chemical Engineering, Professor Mason became a member of the staff of the College of Engineering.

In 1958 he was appointed the Emile M. Chamot Professor of Chemical Microscopy. He and the Late Professor Chamot, under whom he had gotten his doctorate, were pioneers in the founding of the field of chemical microscopy. Professor Mason's special field of interest is the study of microscopical properties and behavior of chemicals, construction materials, and manufactured products. On this subject he has published over forty papers in professional journals.

Dr. Mason has been a consultant to Polarized Lights, Inc.; technical advisor during World War II to the Office of Scientific Research and Development; and project supervisor on confidential research for the United States Army Chemical Corps. He is author of a textbook, *Introductory Physical Metallurgy,* and co-author with E. M. Chamot of the two-volume *Handbook of Chemical Microscopy.*

Professor Mason has been an active member of a number of technical societies including the American Chemical Society. He was founder and first chairman of the Division of Analytical and Microchemistry; an educational lecturer for the American Society for Metals in 1947; and is a member of the American Institute of Mining and Metallurgical Engineers, the American Society for Testing Materials, and the British Institute of Metals. He is an honorary member of the Metropolitan Microchemical Society. He is also a member of Tau Beta Pi, Sigma Xi, and Phi Kappa Phi.

In retirement Dr. Mason expects to devote some time to the pursuit of a favorite hobby, the collection and restoration of antiques.

■ *True McLean,* Professor of Electrical Engineering, Emeritus, was born in Richmond County, New York, and did his preparatory school work at Staten Island Academy. He received the degree of Electrical Engineer from Cornell in 1922. After graduation he was employed by the Western Electric Company in the development and research engineering department, now the Bell Telephone Laboratories.

In 1923 Professor McLean returned to Cornell as an instructor and has served the University faculty for 43 years, rising through the academic ranks to Assistant Professor in 1930, Associate Professor in 1943, and Professor in 1946. He received the professional engineer diploma from the State of New York in 1937.

Professor McLean's special field of interest is communications. He joined Cornell's radio broadcasting station, WHCU, shortly after its founding in 1923 and has contributed to its engineering design over the years, becoming chief engineer in 1940. Other organizations for which he has worked as consultant include the Union Oil Company of Pennsylvania; Radio Station WSYR, Syracuse; Cornell Aeronautical Laboratory; General Electric Company; and Philco Corporation. In 1949–50 he was a consultant at Brookhaven National Laboratory where he worked on the design of the electric drive circuitry for the large proton synchroton.

Professor McLean's hobbies are astronomy, flying, and music. He says that his experience in each of these has been tied in with his professional life. Astronomy and flying combined with his radio engineering led to a course in radio aids to navigation which he gave each year. Astronomy combined with radio engineering has led to a keen interest in the absolute determination of time. Music, according to Professor McLean, has helped his work in acoustics and radio broadcasting.

Professor McLean was recently elected to a second term as president of the Ithaca Chapter of the New York State Society of Professional Engineers. He is a fellow of the Institute of Electrical and Electronics Engineers and a member of the Society of Sigma Xi and Eta Kappa Nu.

He and Mrs. McLean plan to maintain their residence in Ithaca and he will continue his consulting practice using Ithaca as a base.

FACULTY PUBLICATIONS

The following publications and conference papers by members of the Cornell College of Engineering faculty were published during February, March, and April 1966. In cases of co-authorship, the names of Cornell faculty members are in italics.

■ AEROSPACE ENGINEERING

George, A. R., "Nonuniform Hypersonic Flow Past a Wedge," *The Physics of Fluids,* Vol. 9, No. 3 (March 1966), pp. 453–461.

Liboff, R. L., "Brownian Motion of Charged Particles in Crossed Electric and Magnetic Fields," *Physics Review,* Vol. 141, No. 1 (1966), pp. 222–227.

Shen, S. F., "A Simplified Description of Rarefied-Gas Flows by Means of the Hydrodynamic Equations," *Proceedings of International Symposium on Fundamental Phenomena in Hypersonic Flow,* Cornell University Press (1966), pp. 1–18.

■ AGRICULTURAL ENGINEERING

Scott, N. R. and *Johnson, A. T.,* "Progress of Environmental and Physiological Measurements with Poultry," presented at second annual meeting of the Southern Region Avian Environmental Physiology and Bioengineering Study Group, Jackson, Miss., February 6, 1966.

Shaulis, N., Shepardson, E. S. and Jordan, T. D., "The Geneva Double Curtain for Concord Grapes," Bulletin #811, New York State Agricultural Experiment Station, Geneva, N.Y., February 1966.

■ CHEMICAL ENGINEERING

Cocks, G. G., "Chemical Microscopy," *Analytical Chemistry,* Vol. 38, 197R, April 1966.

Coughlin, R. W. and *Von Berg, R. L.,* "Mass and Heat Transfer to Drops in a Mixer-Settler," *Chemical Engineering Science,* Vol. 21 (1966), pp. 3–18.

Midler, M., Jr. and *Finn, R. K.,* "A Model System for Evaluating Shear in the Design of Stirred Fermentors," *Biotechnology and Bioengineering,* Vol. 8 (February 1966), pp. 71–84.

Nicholson, W. J. and *Smith, J. C.,* "Solids Blending in a Fluidized Bed," *Chemical Engineering Progress Symposium Series,* Vol. 62, No. 62, 1966.

Sclar, C. B., Short, N. M., and *Cocks, G. G.,* "Shock-Wave Damage in Quartz as Revealed by Electron and Incident-Light Microscopy," presented at the Conference on Shock Metamorphism of Natural Materials, Goddard Space Flight Center, Greenbelt, Md., April 1966. (Sponsored by: NASA, Carnegie Institution, and U.S. Geological Survey.)

■ CIVIL ENGINEERING

Behn, V. C. and *Monadjemi, P.,* "Developments in Biological Filtration," presented at the Special Lecture Series on Advances in Water Quality Improvement, Center for Research in Water Resources, The University of Texas, Austin, Texas, April 1966.

Dworsky, L. B., "Science-Technology and Environmental Change," presented at the Symposium on Environmental Control, Lafayette College, Easton, Pa., April 1966.

Gergely, P. and *Lutz, L. A.,* "Maximum Crack Width in Reinforced Concrete Flexural Members," presented at the Annual Convention of American Concrete Institute, Philadelphia, March 1966.

Graf, W. H., "On the Determination of the Roughness Coefficient in Natural and Artificial Waterways," *Bulletin of the International Association of Scientific Hydrology,* March 1966.

Hewitt, W. L., Discussion Leader for Engineering Graphics, Upstate New York Workshop on Engineering Science Curricula (Junior and Senior Colleges), Alfred University, Alfred, N.Y., April 1966.

Liggett, J. A. and *Graf, W. H.,* "Steady and Unsteady Effects on Discharge in a River Connecting Two Reservoirs," presented at the Ninth Conference on

Great Lakes Research, Chicago, March 1966.

Loucks, D. P., "A Probabilistic Approach to Stream Standards," *Proceedings of the Fifteenth Annual Water Resources and Pollution Control Conference,* North Carolina State University, Raleigh, N.C., April 1966.

Lyon, G. B., "Professional Education for Land Surveyors—Hope or Reality," presented at the Seventh Annual Conference of New York State Association of Professional Land Surveyors, Rochester, N.Y., January 1966.

McNair, A. J. and Anderson, J. M., "Analytic Aerotriangulation: Triplets and Sub-blocks," presented at the Annual Meeting of the American Society of Photogrammetry, Washington, D.C., March 1966; and at the International Society of Photogrammetry Commission III-Aerotriangulation, International Symposium, University of Illinois, Urbana, Ill., March 1966.

Slate, F. O., "A Qualitative Hypothesis to Explain Entrainment of Air in Concrete," *Cornell Engineer,* Vol. 31, No. 4, pp. 11–14.

White, R. N. and Fang, P. J., "Framing Connections for Square Structural Tubing," *American Society of Civil Engineers, Structural Division, Journal,* Vol. 92, No. ST2 (April 1966), p. 175.

White, R. N. and *Sabnis, G. M.*, Discussion of a paper, "Test of a Reinforced Concrete Flat Plate," *American Society of Civil Engineers, Structural Division, Journal,* Vol. 92, ST2 (April 1966), p. 443.

Winter, G. and Shah, S. P., "Inelastic Behavior and Fracture of Concrete," presented at the meeting of the American Concrete Institute, Philadelphia, March 1966.

■ COMPUTER SCIENCE

Hartmanis, J. and Stearns, R. E., "Algebraic Structure Theory of Sequential Machines," *International Series in Applied Mathematics,* Prentice-Hall, March 1966.

Hartmanis, J., "Context-free Languages and Turing Machine Computations," presented at American Mathematical Society Symposium on Mathematical Aspects of Computer Science, New York, April 1966.

Salton, G., "Data Manipulation and Programming Problems in Automatic Information Retrieval," *Communications of the Association for Computing Machinery,* Vol. 9, No. 3 (March 1966), pp. 204–210.

Salton, G., "Automatic Phrase Matching," *Readings in Automatic Language Processing,* D. Hays (ed.), American Elsevier Publishing Co. (1966), pp. 169–188.

■ ELECTRICAL ENGINEERING

Dalman, G. C. and *Chen, W. T.*, "Gunn Diode Oscillation Modes in Tunable Resonant Cavity Circuits," presented at the Conference on Active Microwave Effects in Bulk Semiconductors, New York, February 1966. (Partially sponsored by the Institute of Electrical and Electronics Engineers.)

DeClaris, N., "A Signal Design Philosophy for High Resolution Radar," *Institute of Electrical and Electronics Engineers Convention Record, Aerospace Systems,* Vol. 14, Part 4, March 1966.

DeClaris, N., "Transformations of the Ambiguity Function," *Institute of Electrical and Electronics Engineers Transactions on Information Theory,* Vol. IT–12, No. 4, April 1966.

Gaarder, N. T., "The Design of Point Detector Arrays, II," *Institute of Electrical and Electronics Engineers Transactions on Information Theory,* Vol. IT–12, No. 4, April 1966.

Gordon, W. E., "Radar Exploration of Space," presented at the Institute of Electrical and Electronics Engineers Highlights Meeting, New York, March 1966.

Gunshor, R. L., "Decay of Space-Charge Waves on Electron Beams," *Journal of Applied Physics,* Vol. 37 (March 1966), p. 1904.

Ingalls, C. E., "The Sensation of Hearing in Electromagnetic Fields," presented at the Seventh Annual Symposium on Space Medicine, Cornell University, Ithaca, N.Y., February 1966.

Jelinek, F., "Determination of Capacity Achieving Input Probabilities for a Class of Finite State Channels with Side Information," *Information and Control*, Vol. 9, April 1966.

Jelinek, F., "Three Signalling Systems for Double Access to an Active Satellite," *Institute of Electrical and Electronics Engineers Transactions on Communication Technology*, Vol. 14, No. 2, April 1966.

Kim, M., "An Optimum Control of Discrete Systems: II," *Instrument Society of America Transactions*, Vol. 5 (April 1966), pp. 184–194.

Kim, M. and *Ramos, J.*, "Implementation of Optimum Sampled Data Control," *Institute of Electrical and Electronics Engineers Transactions on Automatic Control*, Vol. AC–11, April 1966.

Kim, M. and *Erzberger, H.*, "Optimum Distributed Parameter Systems with Distributed Control," *Proceedings of the Institute of Electrical and Electronics Engineers* (Correspondence), Vol. 54 (April 1966), pp. 714–715.

Liboff, R. L., "Reply to Comments by P. P. J. Schram," *Physics of Fluids*, Vol. 9, No. 2 (February 1966), pp. 419–420.

Linke, S., Panel member on discussion of *American Society for Engineering Education Report: Goals for Engineering Education*, Institute of Electrical and Electronics Engineers International Conference, New York, March 1966.

MacKenzie, L. A. and *Shen, C. C.*, "Transit Time Oscillation Performance of Commercial Epitaxial Diodes," Conference on Active Microwave Effects in Bulk Semiconductors, New York, February 1966.

Meserve, W. E., "On a Restricted Class of Linear Time-Varying Sampled Data Systems," *Proceedings of the Institute of Electrical and Electronics Engineers* (February 1966), pp. 289–290.

Statz, H., *Tang, C. L.* and Koster, G. F., "Probabilities for Radiative Transitions in the Carbon Dioxide Laser System," Fourth International Conference on Quantum Electronics, Phoenix, Ariz., April 1966.

Tang, C. L., "Saturation and Spectral Characteristics of the Stokes Emission in the Stimulated Brillouin Process," Fourth International Conference on Quantum Electronics, Phoenix, Ariz., April 1966.

Thorp, J. S. and *Mintz, M.*, "A Method of System Identification with Random Inputs," *Proceedings of the Institute of Electrical and Electronics Engineers*, February 1966.

Torng, H. C., "Single Threshold Device Realization Subject to Sensitivity Requirements," *Journal of the Franklin Institute*, Vol. 281, No. 2, February 1966.

Torng, H. C., "An Approach for the Realization of Linearly-Separable Switching Functions," *Institute of Electrical and Electronics Engineers Transactions on Electronic Computers*, Vol. EC–15, No. 1 (February 1966), pp. 14–20.

Wolga, G., "Multiple Quantum Processes and Higher Order Correlation Functions," *Physical Review Letters*, Vol. 16, No. 14 (1966), p. 625.

Zimmerman, S. W., Cassidy, E. C. and Newman, K., "Time Resolved Electrical Measurements in High Current Discharges," *Review of Scientific Instruments*, Vol. 37, No. 2 (February 1966), pp. 210–214.

■ ENGINEERING PHYSICS

Desai, R. C. and *Nelkin, M.*, "Atomic Motions in a Rigid Sphere Gas as a Problem in Neutron Transport," *Nuclear Science and Engineering*, Vol. 24 (February 1966), p. 142.

Gelhaus, F. E. and *Howe, J. P.*, "The Cesium Thermionic Converter Interelectrode Electron Density Distribution as Determined by Radiation Transport," *Proceedings, MIT Physical Electronics Conference* (Abstract in *Bulletin of American Physical Society*), Cambridge, Mass., March 1966.

Herman, D. S. and *Rhodin, T. N.*, "Electrical Conduction Between Metallic-Microparticles," *Journal of Applied Physics,* Vol. 37, No. 4 (1966), p. 1596.

Nelkin, M. and Yip, S., "Brioullin Scattering by Gases as a Test of the Boltzmann Equation," *Physics of Fluids,* Vol. 9 (February 1966), p. 380.

Robins, J. L., Gerlach, R. L. and *Rhodin, T. N.,* "Kikuchi Effects from Low Energy Electrons in Nickel," *Applied Physics Letters,* Vol. 8, No. 1 (1966), p. 12.

Rollins, R. W. and *Silcox, J.,* "Critical Currents in the Superconducting Sheath of Pb-In Alloys as Measured by Low Frequency a-c Field Penetration," *Bulletin of the American Physical Society,* Vol. II (1966), p. 224.

■ INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Conway, R. W., "A Language Processor for Introductory Engineering Computation," presented at the Conference, "Impact of Computers on Education in Engineering Design," Commission on Engineering Education, University of Illinois, Chicago, April 1966.

■ MATERIALS SCIENCE AND ENGINEERING

Batterman, B. W. and Patel, J. R., "Effect of Compressive Stress on the Low Temperature Transformation and Softening in V_3Si," presented at the Meeting of the American Physical Society, Durham, N.C., March 1966.

Blakely, J. M. and *Li, C. Y.,* "Changes in Morphology of Ionic Crystals Due to Capillarity," *Acta Metallurgica,* Vol. 14 (1966), p. 279.

Burton, M. S., "The Cornell Materials Curriculum and the ASEE 'Goals Report,'" presented at the Purdue Conference on Metallurgical Education, Lafayette, Ind., April 1966.

Formby, C. L. and *Owen, W. S.,* "The Binding Energy of Oxygen to a Dislocation in Tantulum," *Philosophical Magazine,* Vol. 13, No. 121 (January 1966), p. 41.

Hancock, G. G. and *Johnson, H. H.,* "Hydrogen, Oxygen, and Subcritical Crack Growth in a High Strength Steel," *Transactions of the American Institute of Mining, Metallurgical and Petroleum Engineers,* Vol. 236 (April 1966), p. 513.

Johnson, H. H., "Strain Energy of Screw Dislocation Arrays," *Journal of Applied Physics,* Vol. 37, No. 4 (March 1966), p. 1263.

Seidman, D. N. and *Baluffi, R. W.,* "On the Annealing of Dislocation Loops by Climb," *Philosophical Magazine,* Vol. 13 (March 1966), p. 649.

■ MECHANICAL ENGINEERING

Cool, T. A. and Zukoski, E. E., "Recombination, Ionization and Non-equilibrium Electrical Conductivity," *The Physics of Fluids,* Vol. 9 (April 1966), p. 780.

Moore, F. K., "Effect of Radiative Transfer on a Sound Wave Traveling in a Gas Having Gamma Near One," *The Physics of Fluids,* Vol. 9, No. 1 (January 1966), pp. 70–80.

Moore, F. K., "Radiative Transfer," presented at UCLA Short Course, "Reentry and Planetary Entry—Physics and Technology," Los Angeles, February-March 1966. (Lecture notes to be published by UCLA Engineering Extension in book form.)

■ THEORETICAL AND APPLIED MECHANICS

Conway, H. D., "Thermoelastic Stresses in Strips and Cylinders," *Archives de Mécanique Appliquée* (Polish Academy of Sciences), Vol. 18, Part 2, 1966.

Lance, R. H. and Rickert, D. W., "Limit Analysis of a Spherical Cap Using Linear Programming," presented at the Third Southeastern Conference on Theoretical and Applied Mechanics, University of South Carolina, Columbia, S.C., March-April 1966.

Pao, Y. C. and *Conway, H. D.,* "An Optimum Study of the Antielastic Deformations of Strips with Tapered Edges," *International Journal of Mechanical Sciences,* Vol. 8, No. 2 (February 1966), pp. 65–76.

Engineering New Materials

In Editorial Conference: University Editor Donald J. Mainwaring, Quarterly Editor Donald F. Berth, Designer Lynda A. Thompson, Copy Editor Bettye S. Elkins, and Quarterly Editorial Assistant Mrs. K. Toby Clarey.

ENGINEERING: Cornell Quarterly

Editor: Donald F. Berth

Editorial Assistant: K. Toby Clarey

Produced and designed by the Office of University Publications.

 Please address any correspondence, including notification of change of address, to ENGINEERING: Cornell Quarterly, Carpenter Hall, Ithaca, New York 14850.

The increased tempo of production of radically new materials, particularly in our present decade, suggests that a highly successful interaction has taken place between those engineers and scientists interested in materials. Materials science is a rapidly evolving discipline relating the principles of physics and chemistry to materials; materials engineering, with its origin in metallurgical engineering, relates the selection, processing, and application of materials for specific needs.

Our capability to understand the structure of materials through observational techniques has been extended from simple external observation of crystalline structure through electron microscopy, to modern techniques such as x-ray topography. Along with advances in our knowledge of materials structure, new working environments, such as outer space, require new engineering abilities to fabricate materials not found among common metals and alloys.

Today's knowledge of materials and the challenges of new environments have, in fact, introduced a new type of engineer, one required to work at both the research and application interfaces. While the Department of Materials Science and Engineering is a newcomer to Cornell's list of engineering schools and departments, it has already experienced dramatic growth, stimulated in part by the outstanding facilities in Bard Hall and at the interdisciplinary Materials Science Center. The Center, housed in Clark Hall, was established with funds from the Advanced Research Projects Agency, Department of Defense.

The Faculty of the College is very much aware of the extending range over which modern engineers function. There is an excitement in educational "pioneering," and Cornell's Materials Science and Engineering Department is doing just that today through its efforts to educate this new breed of engineer.

THE EDITOR

ENGINEERING'S format: The four photographs selected to appear on our covers have been keyed to the four articles that appear in each issue. Through them and through the article annotations on the inside title page, our readers should find it easier to recall the contents of issues already read. *The color of our cover and title accents will change with each issue and will be seasonal.* However, a hot red, rather than our cool blue, would perhaps have better reflected Ithaca's summer weather this year!

If we do not already have your correct zip code, please let us know. Beginning in January, 1967, we cannot mail ENGINEERING to a non-zip-coded address.